

THE EFFECTS OF HIGH TURBULENCE IN THE INTAKE MANIFOLD
ON THE PERFORMANCE OF AN OTTO CYCLE ENGINE

A THESIS

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by
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APPROVED:







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Sept 14, 1951

ACKNOWLEDGMENTS

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LIST OF ABBREVIATIONS AND SYMBOLS

t	Length of run in minutes.
N	Engine speed in revolutions per minute.
W_f	Pounds of gasoline burned per run.
SA	Spark advance in degrees.
L	The load on the dynamometer scale in pounds.
WB	Wet-bulb temperature.
DB	Dry-bulb temperature.
BP	Barometric pressure.
MP	Intake manifold pressure in inches of mercury, absolute.
h_w	Pressure drop across orifice, for measuring the weight of air entering the engine, in inches of water.
A/F-1	Air-fuel ratio for the number one cylinder.
A/F-2	Air-fuel ratio for the number two cylinder.
A/F-3	Air-fuel ratio for the number three cylinder.
A/F-4	Air-fuel ratio for the number four cylinder.
A/F-5	Air-fuel ratio for the number five cylinder.
A/F-6	Air-fuel ratio for the number six cylinder.
BHP_c	Brake horsepower corrected to standard atmospheric pressure and temperature (29.92 " Hg. and 60°F).
A/F_c	Air-fuel calculated from the measurement of air and fuel used during some period of time.
P_a	Pressure drop across variable-area mechanism measured in inches of water.
CM	Conventional-type intake manifold.

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

NM	New-type intake manifold.
NL	No load.
BHP	Brake horsepower.
q_f	Heating value of gasoline, 20,300 Btu/pound.
P_s	Standard atmospheric pressure, 29.92"Hg.
P_a	Atmospheric pressure measured during test runs.
t_s	Standard atmospheric pressure, 60°F.
t_a	Room temperature measured during test runs.
C_d	Discharge coefficient for thin plate orifice.
F	Approach factor for orifice.
A	Area of orifice.
v_1	Specific volume of air at room conditions, cubic feet per pound.

THE EFFECTS OF HIGH TURBULENCE IN THE INTAKE MANIFOLD
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INTRODUCTION

Purpose:

The purpose of this investigation is to determine the effects of high velocities of the air-fuel mixture in the intake manifold upon the distribution to the cylinders of a multi-cylinder internal combustion engine operating on the Otto cycle. Also, it is desired to determine the effect of obtaining these high velocities upon the performance of the engine.

Objective:

The object of this investigation is to obtain sufficient data from the operation of an internal combustion engine operating on the Otto cycle using the conventional type intake manifold and using a new-type intake manifold designed to produce high velocities and high turbulence of the air-fuel mixture to plot the performance curves. From an analysis of these curves a conclusion can be formed regarding the effects of high turbulence in the air-fuel mixtures upon the performance of the engine.

An outstanding fault of the intake manifold of multi-cylinder internal combustion engines operating on the Otto cycle is the non-uniform distribution of air-fuel mixtures

to the cylinders. This is extremely noticable at low engine speeds and at part load. Under these operating conditions the pressure in the intake manifold is quite low. At the time the intake valve begins to open to admit a fresh charge the pressure in the cylinder is atmospheric or slightly above and the result is the flow of exhaust gas into the intake manifold. As the piston proceeds on its downward stroke this exhaust gas plus fresh charge is brought into the cylinder. Since the ratio of exhaust gas to fresh charge is considerable, a fuel-rich mixture must be maintained for smooth operation. Also, since the intake manifold must be designed large enough to supply sufficient charge to the cylinders at full throttle setting without appreciable pressure drops, it is obvious that at low engine speeds and aprt load the velocities in the manifold are quite low. Due to the fact that all the gasoline does not evaporate between the carburetor and the cylinders, there are droplets of liquid gasoline carried along in the air stream. Due to the low stream velocities and the relative weights of air and gasoline, the droplets of gasoline do not make the turns necessary to enter the center cylinders of the engine but are carried along with the air stream to the end cylinders giving a richer mixture in these cylinders than in the center ones. In order to have a smooth-operating engine it is necessary for the carburetor to supply a mixture that is rich enough to give good combustion in the center

cylinders, resulting in an over-rich mixture in the end cylinders. If uniform distribution of air and fuel to the cylinders could be achieved, then the mixture leaving the carburetor could be made leaner and an increase in engine thermal efficiency would result.

It would seem reasonable that, if an intake manifold could be designed whose cross-sectional area near the carburetor could be varied to give high velocities to the air-fuel stream at all engine speeds and loads, the faults found in the conventional-type intake manifold could be overcome to a certain extent, giving a more uniform distribution to the cylinders. The intake manifold (which will be referred to throughout this thesis as the new-type intake manifold) which is to be used in this investigation is designed with a manually-controlled mechanism, the use of which makes it possible to obtain high velocities of the air-fuel stream over the complete range of engine speeds and loads. Since normal automotive engine operation is in the range from no load to one-half load, this range will be given special emphasis in this investigation.

APPARATUS

Engine:

The engine used for this test was a 1948 Chevrolet passenger automobile engine. A Taylor hydraulic dynamometer was used to absorb the energy produced by the engine and to measure the power output. This equipment is installed in the Mechanical Engineering Laboratory. The engine specifications are:

Bore, inches-----	3.5
Stroke, inches-----	3.75
Displacement, cubic inches-----	216.5
Compression ratio-----	6.6 to 1
Number of cylinders-----	6

Ignition System:

The engine had the usual type ignition system used on spark ignition engines, including storage battery, breaker points, and coil arrangement. Both the vacuum and the centrifugal spark advance mechanisms were removed from the distributor and the breaker-point cam was rigidly attached to the shaft which drives it. A plate was made and stamped with the actual degrees of spark advance with reference to the engine crankshaft. This plate was rigidly fastened to the engine block. A pointer was fastened to the distributor and was adjusted to indicate zero degrees spark advance when the piston was in the top dead center position on the compression stroke. The spark plugs were the type specified by

the engine manufacturer and were cleaned and checked for clearance before the test runs (using each of the two intake manifolds) were made.

Fuel System:

The fuel system consisted of the standard equipment for this type engine which included a Carter down draft Carburetor and a diaphragm type fuel pump. A two gallon can connected to the system by a flexible rubber hose was used as a fuel tank. The two gallon can rested on a Toledo scales which could be read accurately to a hundredth of a pound.

Connected to the upstream side of the carburetor was a four inch air duct in which was fixed a thin-plate orifice of 1.50 inches diameter. Vena Contracta Pressure taps were used. The weight of air flowing into the engine was measured by use of this orifice.

Instrumentation:

Gages indicating oil pressure and manifold pressure were mounted on the engine instrument panel. A Metron tachometer was used to measure engine speed. For pressure drops across the air intake orifice up to 6.4 inches of water were measured with a micro-manometer which could be read accurately to three decimal places. For pressure drops greater than 6.4 inches of water, an ordinary U-tube water-filled manometer was used. An ordinary automotive thermostat was placed in the cooling system which maintained a

cooling water outlet temperature of 155°F for all loads and speeds.

An exhaust gas sampling tube for each cylinder was arranged in the exhaust manifold so that the end of the tube reached to within one-fourth of the exhaust valve stem and directly above the valve head. The purpose of these tubes was to get an exhaust gas analysis from each cylinder to determine the uniformity of air-fuel mixtures throughout the 6 cylinders.

The new-type intake manifold included a mechanism by which the cross-sectional area of the manifold immediately downstream of the carburetor could be manually varied. This allowed part of the pressure drop from atmospheric pressure to intake manifold pressure to be taken across the throttle valve and the remaining drop across the variable area mechanism. The absolute pressure at a point between the throttle valve and the variable-area mechanism was measured, making possible the determination of the pressure drop across this mechanism.

A Sun Motor Analyzer, manufactured by the Sun Electric Corporation, was used as a fast, convenient method of analyzing the exhaust gas from each individual cylinder.

TEST PROCEDURE

A series of test runs were made on the engine using the conventional type intake manifold, and then these same test runs were made using the new-type intake manifold. The test runs included a "no load", $1/8$ throttle, $1/4$ throttle, $1/2$ throttle, and full throttle power settings. For each throttle setting, the engine was run at the lowest speed the dynamometer could maintain (which varies from 500 to 1200 r.p.m. for $1/8$ throttle and full throttle, respectively), and the speed was increased by 500 r.p.m. per run up to a speed of 3,000 r.p.m. For each throttle setting and engine speed, the air-fuel mixture was varied from an excessively lean mixture to an excessively rich mixture in four steps.

Since the load on the dynamometer scale, weight of fuel used, time of run, and pressure drop across the air intake orifice were measured for runs using these air-fuel mixtures, it was possible to calculate and plot thermal efficiency against air-fuel ratios to determine the point at which the maximum thermal efficiency occurred. This procedure was followed for the $1/8$, $1/4$, and $1/2$ throttle settings using both conventional and new-type intake manifolds. Essentially the same procedure was followed for the "no load" runs (both type intake manifolds) with the exception that the weight of fuel per hour was plotted against air-fuel ratios, the minimum point of each curve indicating the point

of maximum economy.

During the full throttle runs on both manifolds the maximum power was desired. This was obtained by varying the air-fuel mixture at the carburetor (adjusting the metering rod) until maximum load was indicated on the dynamometer scale. This procedure was repeated for each speed during the full-throttle runs. Throughout all test runs the ignition spark was advanced to a point at which maximum load was indicated on the dynamometer scale.

During the test runs using the new-type intake manifold, the problem of making the correct adjustments on the variable-area mechanism was solved as follows. Exhaust gas samples from each cylinder were analyzed with the Combustion Meter of the Sun Motor Tester when there was no pressure drop across the variable-area mechanism. This was repeated with pressure drops (in. Hg.) of 2, 4, 6, 8, etc., and the pressure drop was found at which the most uniform distribution of air-fuel mixtures to the cylinders was obtained. Usually, this optimum pressure drop was approximately half the difference between atmospheric and intake manifold pressure.

The test runs were not of any particular duration, but their length was determined largely by the time required to take all the readings and to take the six exhaust gas samples. In all cases, this was long enough to insure that a weight of fuel was used such that dependable results could

be obtained from the calculations.

DISCUSSION

Power settings throughout this thesis are given as $1/8$, $1/4$, etc., throttle settings. These power settings were arrived at in the following manner: The engine was operated at no load, and speeds over the range of 400 to 3000 RPM, and an average intake manifold pressure was obtained. Then the engine was operated at wide open throttle and speeds ranging from 1000 to 3000 RPM, and an intake manifold pressure was obtained. The half-throttle power setting was arbitrarily assigned as the intake manifold pressure (17.25 "Hg.) obtained by adding to the no load manifold pressure half the difference between no load and full load manifold pressure. In a like manner the $1/8$ (12.10 "Hg.) and $1/4$ (14.30 "Hg.) throttle settings were obtained by adding to the no load manifold pressure $1/8$ and $1/4$ of the pressure difference, respectively.

The data is divided into three groups, which are Group A, Group B, and Group C. Group A is made up of Tables I and II which include observed data and calculated data, respectively, for the conventional-type intake manifold. Group B includes Tables III and IV which consist of observed data and calculated data, respectively, for the new-type intake manifold. Group C is made up of Tables V and VI which include observed data and calculated data, respectively, for check-runs on the conventional-type intake manifold.

Figures 6 through 9 give a comparison of the mixture distribution for the new-type and conventional-type intake manifolds for speeds ranging from 400 to 3000 RPM and loads ranging from no load to half throttle.

Figures 16 and 23 are plots of pounds of fuel per hour against air-fuel ratio (calculated from weight of air and fuel) for the conventional and new-type intake manifolds, respectively, with the engine operating at no load. These curves were obtained by varying the air-fuel mixture at the carburetor in four steps for each engine speed. Measurements of air, fuel, and length of run were made for each mixture, making possible the calculation of data for four points. The minimum point was taken from each curve and these values of fuel consumption were plotted against engine speed (Figure 11) indicating maximum economy at no load operation.

Figures 17 through 22 and 24 through 29 are plots of thermal efficiency against calculated air-fuel ratios for the conventional and new-type intake manifolds, respectively. These curves were obtained in a manner similar to that for the no load runs, differing only in the fact that the power developed by the engine was measured and thermal efficiency calculated. The maximum points from the curves for each throttle setting were plotted against engine speed (Figures 12, 13, 14 for 1/8, 1/4, and 1/2 throttle, respectively), these curves indicating maximum thermal efficiencies for corresponding throttle settings

During the full-throttle runs only maximum power was desired. The effect of the new-type intake manifold on the maximum power developed by the engine was desired to be determined. A comparison of maximum power output of the engine using each of the manifolds is shown in Figure 10. To obtain maximum power output at full-throttle conditions, the carburetor was adjusted until maximum load was shown on the dynamometer scale. Then the ignition spark was adjusted until maximum load was indicated by the dynamometer scale. Consequently, the efficiency curves (Figure 15) plotted for this throttle setting do not indicate maximum efficiency but, instead, show efficiency at maximum power output.

Up to this point, the curves referred to above could be very misleading. This is explained as follows: all the test runs using the conventional-type intake manifold were made first. Then the new-type intake manifold was installed on the engine. Before any runs could be made on this manifold, an undergraduate laboratory class ran tests on the engine which consisted of determining the effects of ignition spark variation on engine performance. The spark was retard to 40 degrees past top center while the engine was operating at high speeds and near full-throttle setting. The result was that several of the exhaust valves were burned until they would no longer seat. This required that the engine be taken apart and the valves ground.

With the engine in a different mechanical condition, the remainder of the test runs (the complete test of the new manifold) were made. Upon completion of these runs, the new manifold was removed and the conventional one reinstalled. Then runs were made on the engine to determine the effect of the valves having been ground. The observed and calculated data for these check runs is given in Group C, Tables V and VI, respectively. Figure 30 shows a plot of thermal efficiency against engine speed for the $1/8$ and $1/4$ throttle settings, these being the power settings at which the check runs were made. A comparison of these curves to those in Figures 12 and 13 shows that the engine condition was changed considerably when the valves were ground.

Since the range of loads and speeds was wide during the test runs, the weight of air taken into the engine varied considerably. This necessitated the use of two orifices in the intake scoop for measuring the weight of air entering the engine. An orifice of 1.000 inch diameter was used for low load operation; in the tabulated data the pressure drops measured across this orifice are followed by an asterisk. For all other load conditions an orifice of 1.50 inch diameter was used.

The combustion meter on a Sun Motor Tester was used to analyze the products of combustion from individual cylinders since a great amount of time would have been required to make orsat analyses of the many samples taken. It

is to be pointed out that the values of air-fuel ratios obtained by use of the Sun Motor Tester are inaccurate as concerns absolute values. However, this combustion meter was found to be consistent, and, therefore, gives a good indication of the uniformity of mixture distribution.

CONCLUSION

Due to the undesirable conditions under which this investigation was carried out, very few definite conclusions can be drawn. A comparison of the $1/8$ and $1/4$ throttle check-runs (see Figure 30) with the corresponding runs in Figures 12 and 13, respectively, indicates that no conclusion can be made as concerns the increase or decrease in thermal efficiency of the engine brought about through use of the new-type intake manifold.

However, from a comparison of the distribution curves shown in Figures 6, 7, 8, and 9 for no load, $1/8$, $1/4$, and $1/2$ throttle settings, respectively, a definite trend seems to have been established. For the no load series of runs, the new-type manifold appears to have given more uniform distribution at the lower speeds (400 and 1000 RPM), but at higher speeds the distribution given by this manifold is not as good as that of the conventional-type manifold. This conclusion is also apparent for the $1/8$ throttle test runs. But for the $1/4$ throttle series of runs, the new-type manifold definitely did give better distribution throughout the range from 500 through 2500 RPM. In this range of speeds the distribution is seen to have varied only very slightly from uniform. This trend is also definitely shown by the curves for the $1/2$ throttle run, Figure 9. Over the range 1000 through 2500 RPM the distribution was improved considerably through use of the new-type manifold.

It is noticed that for all four throttle settings (no load, $1/8$, $1/4$, and $1/2$), the Sun Motor Combustion analyzer indicated a leaner mixture for the new-type intake manifold runs than for those of the conventional manifold. The points for each of the curves shown in Figures 6 through 9 represent the distribution found in the run which gave a thermal efficiency (for each speed) nearest the peak of the curves plotted in Figures 17 through 29. The leaner mixtures obtained through use of the new-type manifold are possibly due to the fact that maximum thermal efficiency was found to occur at a leaner mixture after the engine condition had been improved.

It is also seen that the test runs made on the new-type intake manifold, in general, were made at ignition-spark settings which were advanced a greater number of degrees than for corresponding runs using the conventional intake manifold. The writer has no logical explanation for this fact.

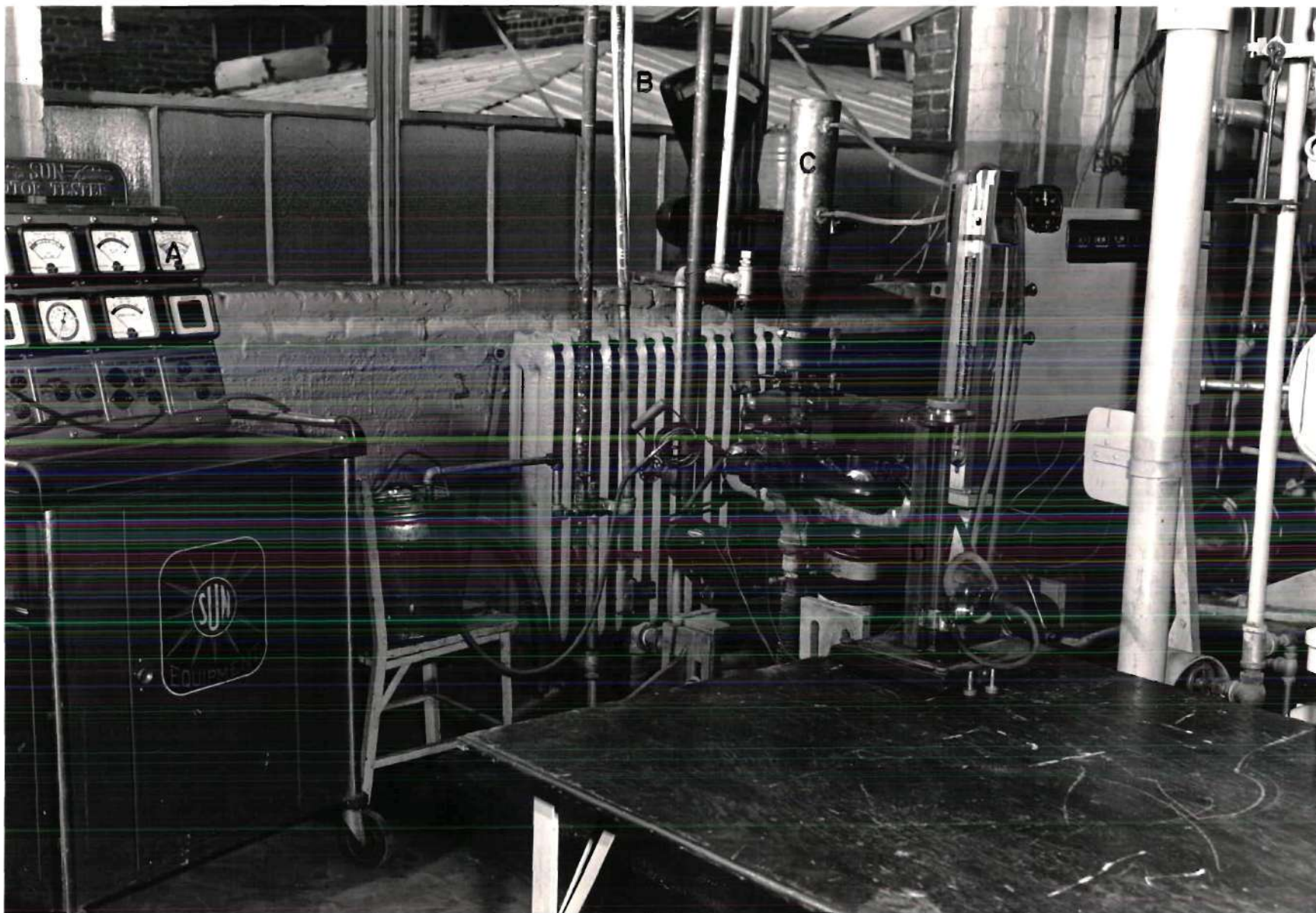
There is a good possibility that if the conventional manifold were subjected to these same test runs again and the data and curves obtained compared with those contained in this thesis for the new-type manifold, the faults and advantages of the latter could be definitely determined.

BIBLIOGRAPHY

- Ebaugh, Newton C., Engineering Thermodynamics. New York: D. Van Nostrand Company, Inc., 1937. pp 117-120.
- Obert, Edward F., Internal Combustion Engines. Scranton, Pennsylvania: International Textbook Company, 1950 596 pp.
- Polson, J. A., Internal Combustion Engines. New York: John Wiley and Sons, Inc., 1942. 554 pp.
- Taub, Alex, "Mixture Distribution", Journal of the Society of Automotive Engineers. 26: 450-470, April, 1930.
- Best, H. W., "Report on Air-Fuel-Ratio Tests", Journal of the Society of Automotive Engineers. 25: 532-533, November, 1929.
- D'Alleva, B. A., and Lovel, W. G., "Relation of Exhaust Gas Composition to Air-Fuel Ratio", Journal of the Society of Automotive Engineers. 38: 90-98, March, 1936.
- Jennings, Burgess H., and Obert, Edward F., Internal Combustion Engines. Scranton Pennsylvania: International Textbook Company, 1944. pp 42-43

APPENDIX I

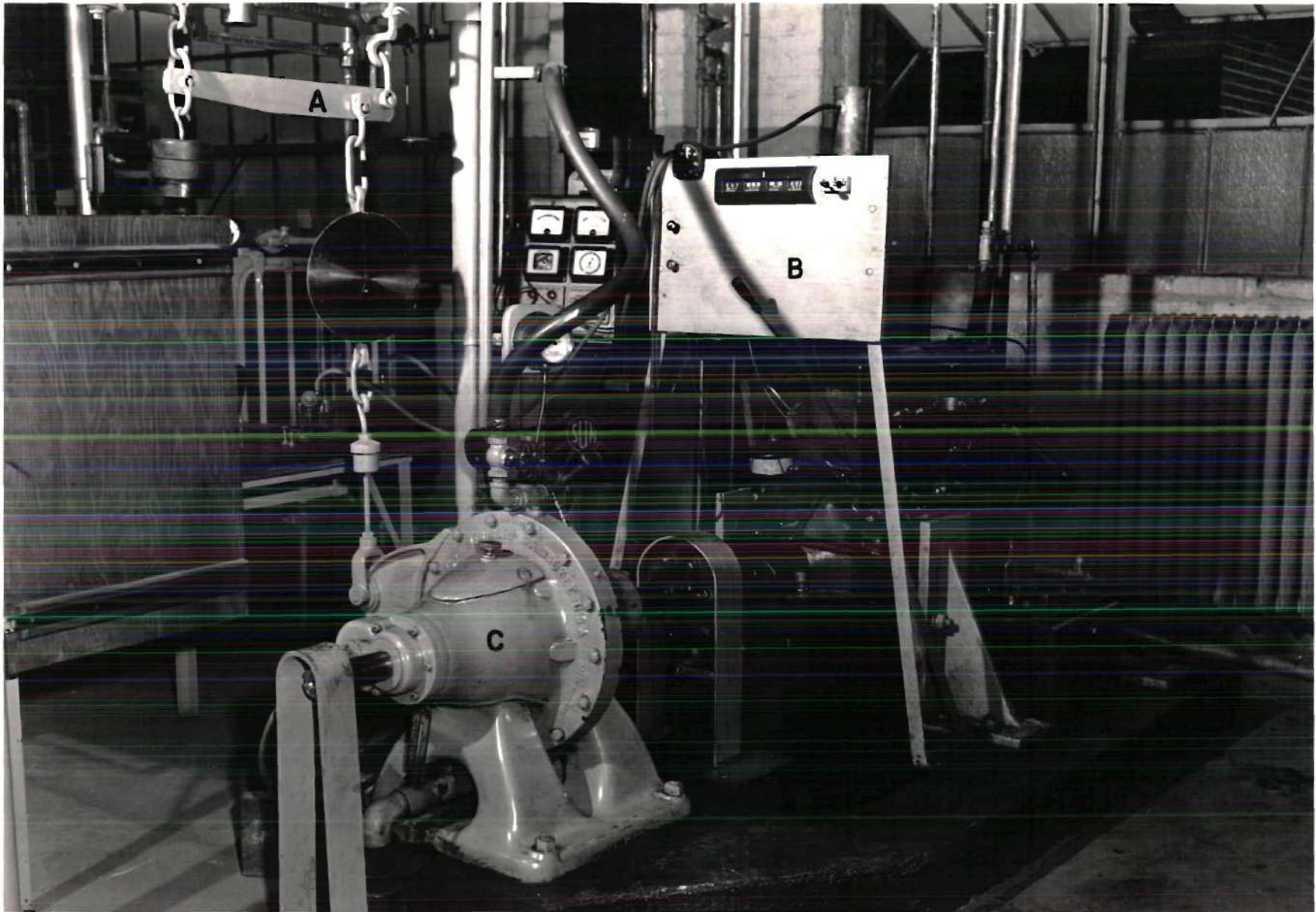
FIGURES



A - Combustion Meter
B - Scale For Weighing Fuel
C - Air Intake Scoop and Orifice

FIGURE 1

D - Micromanometer
E - Exhaust Gas Pickup



A - Dynamometer Scale
C - Dynamometer

FIGURE 2

B - Instrument Panel

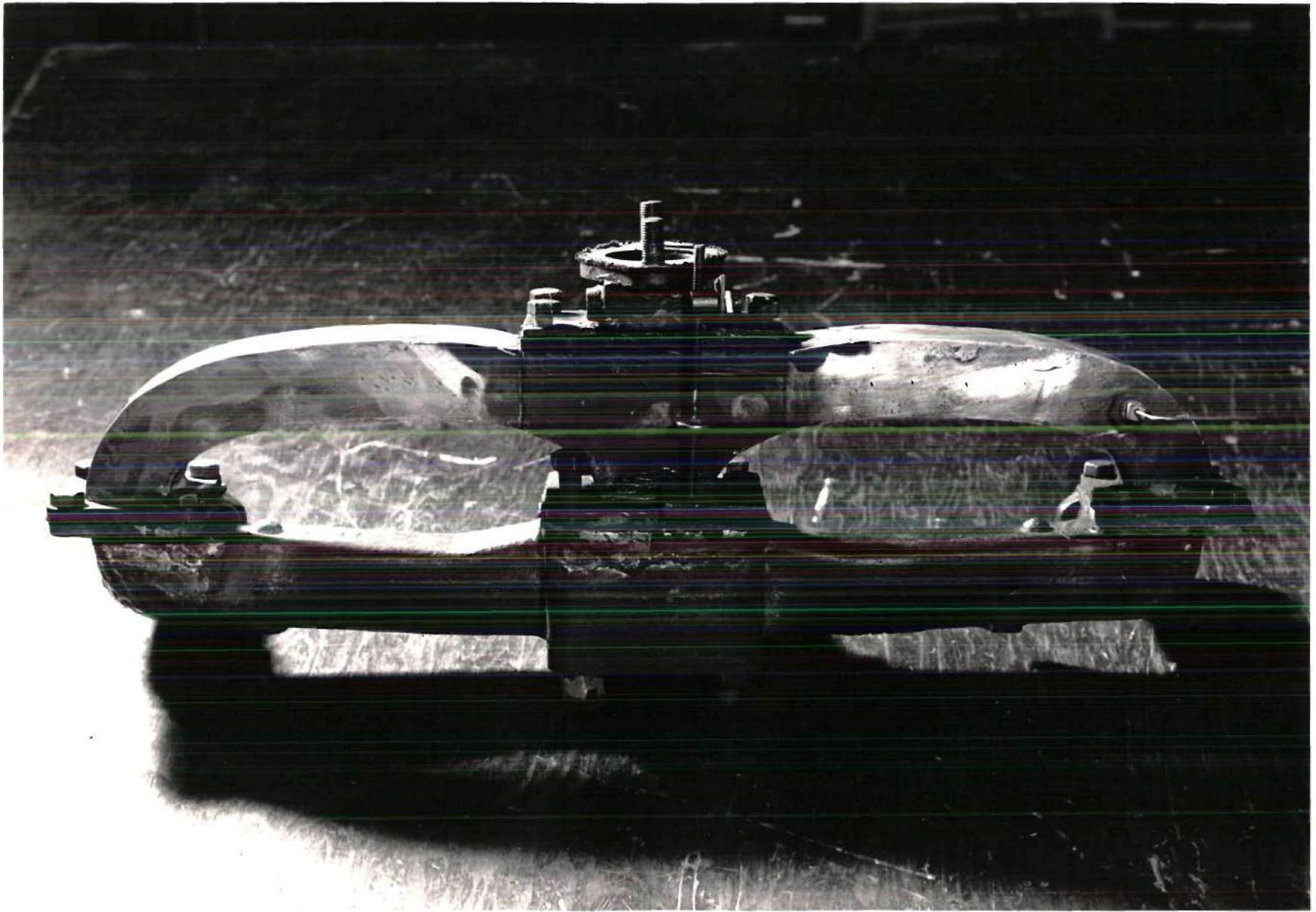
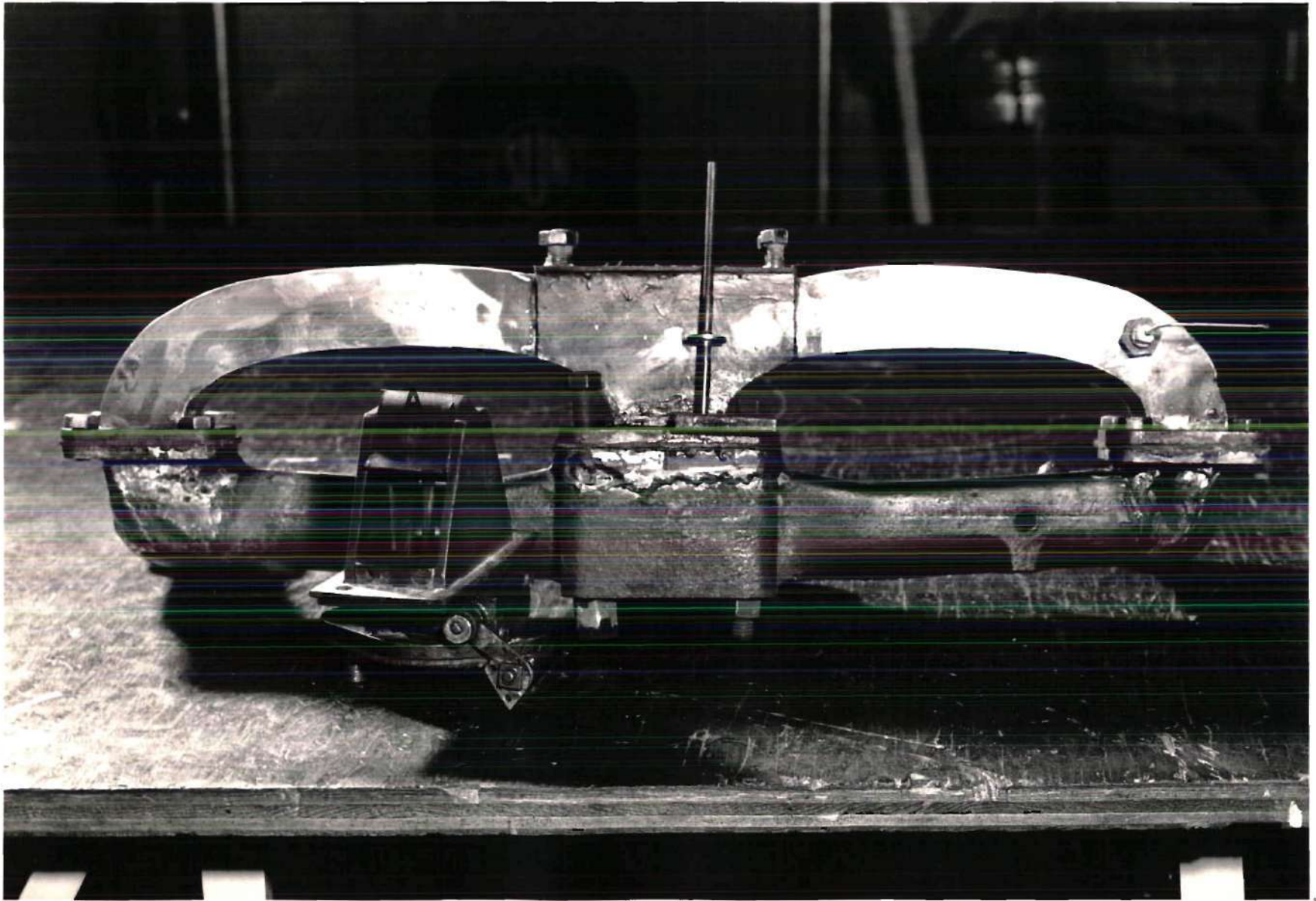


FIGURE 3



A - Variable-area Mechanism

FIGURE 4

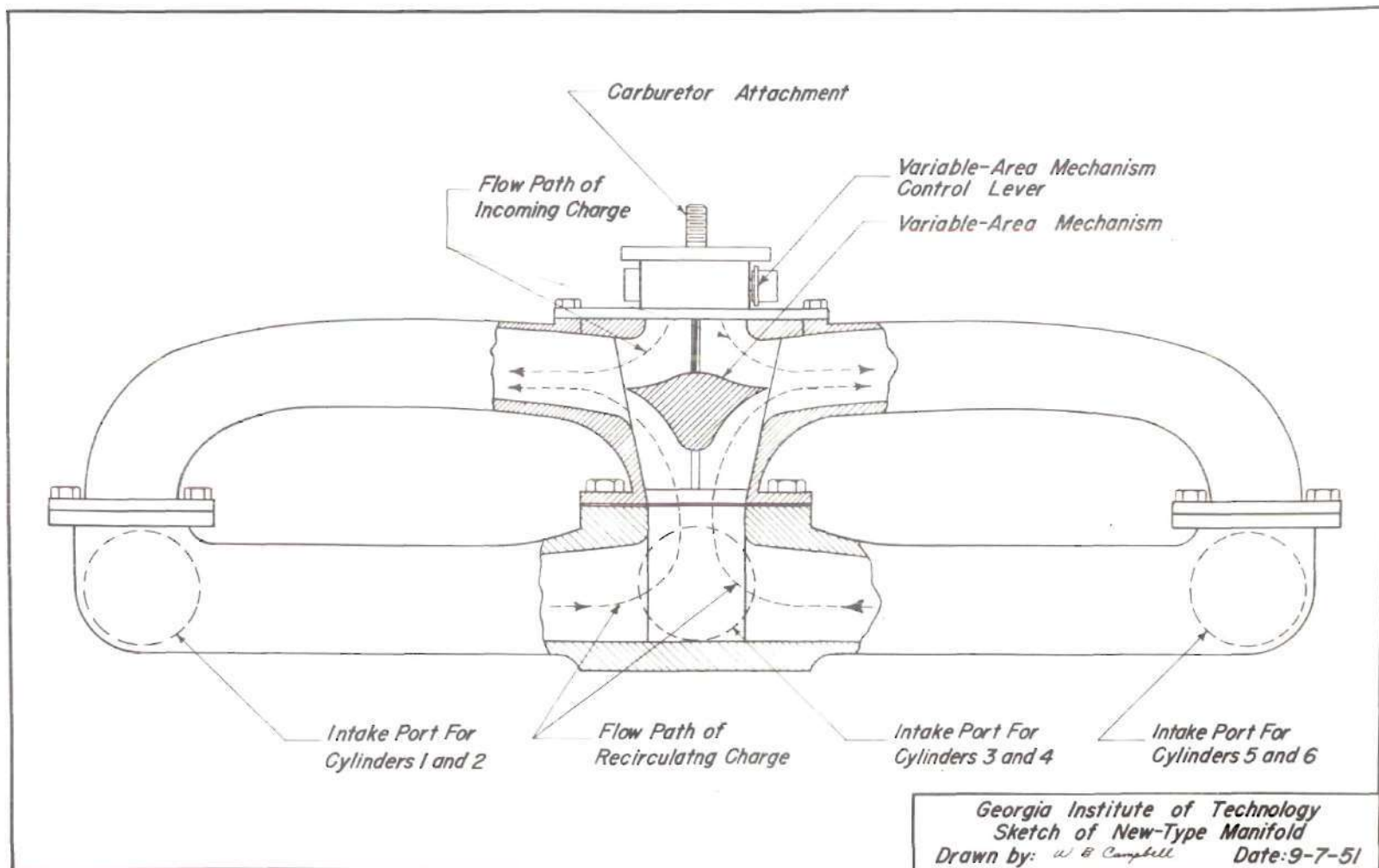


FIGURE 5

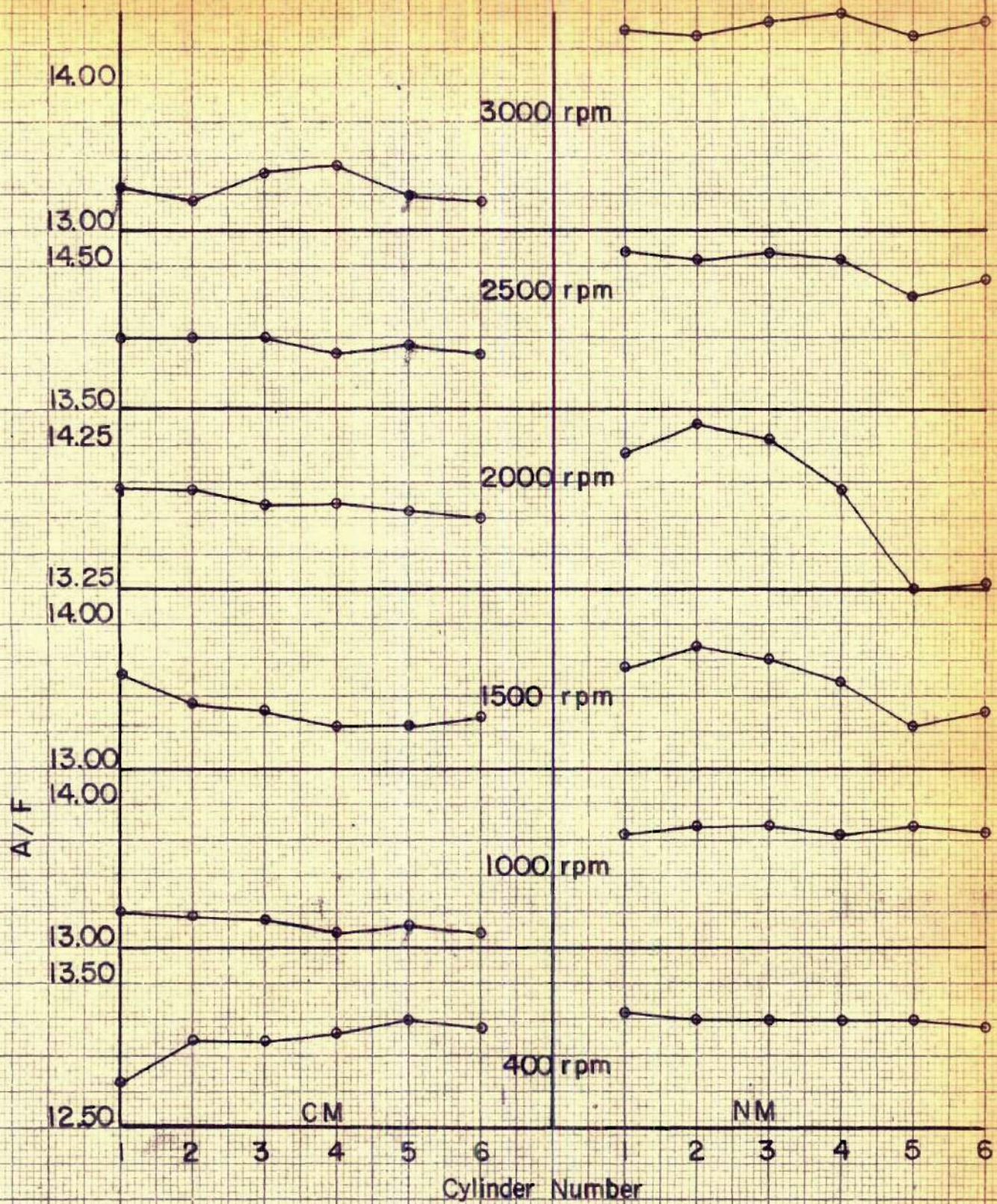


FIGURE 6
No Load

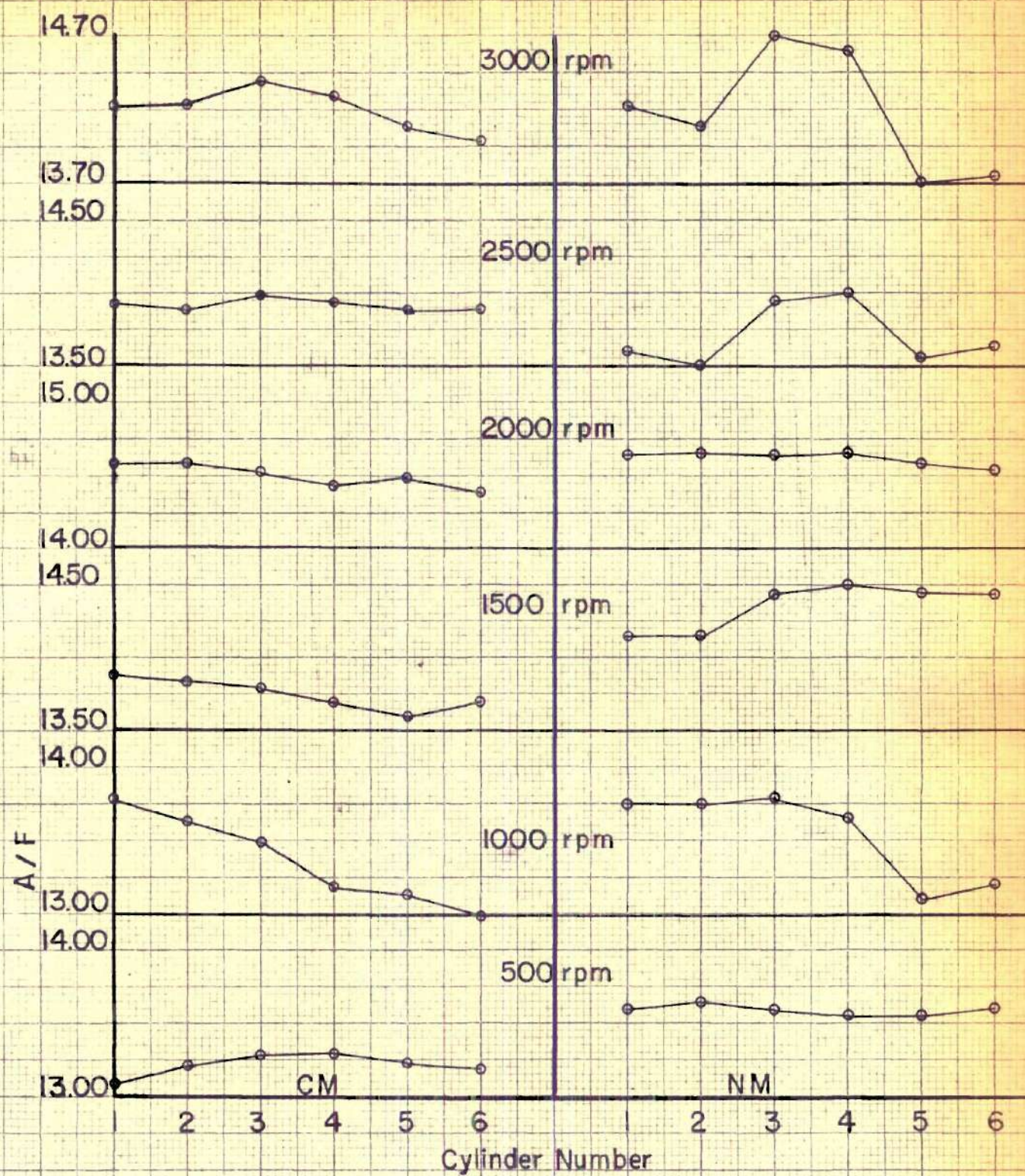


FIGURE - 7
1/8 Throttle

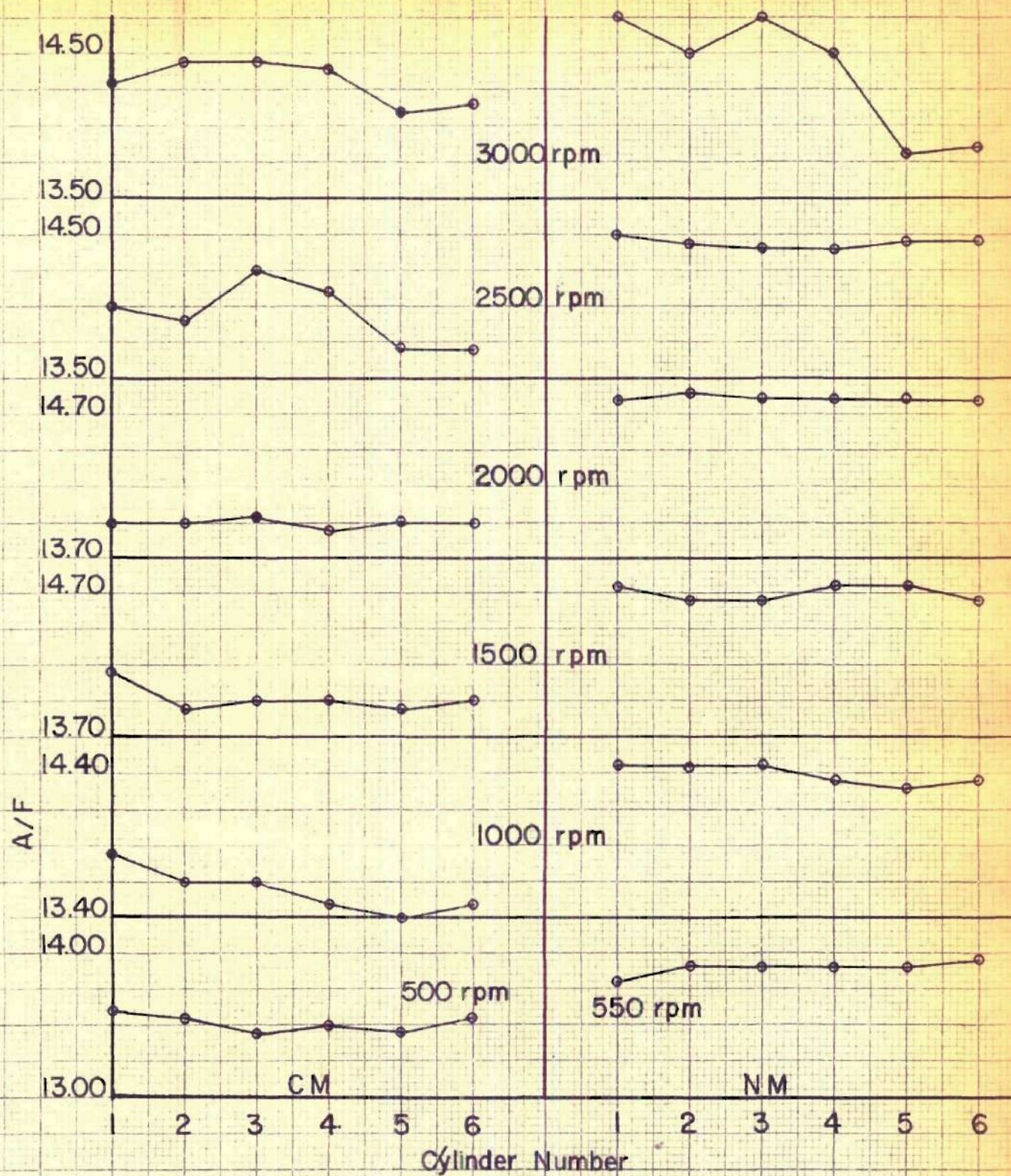


FIGURE 9
1/4 Throttle

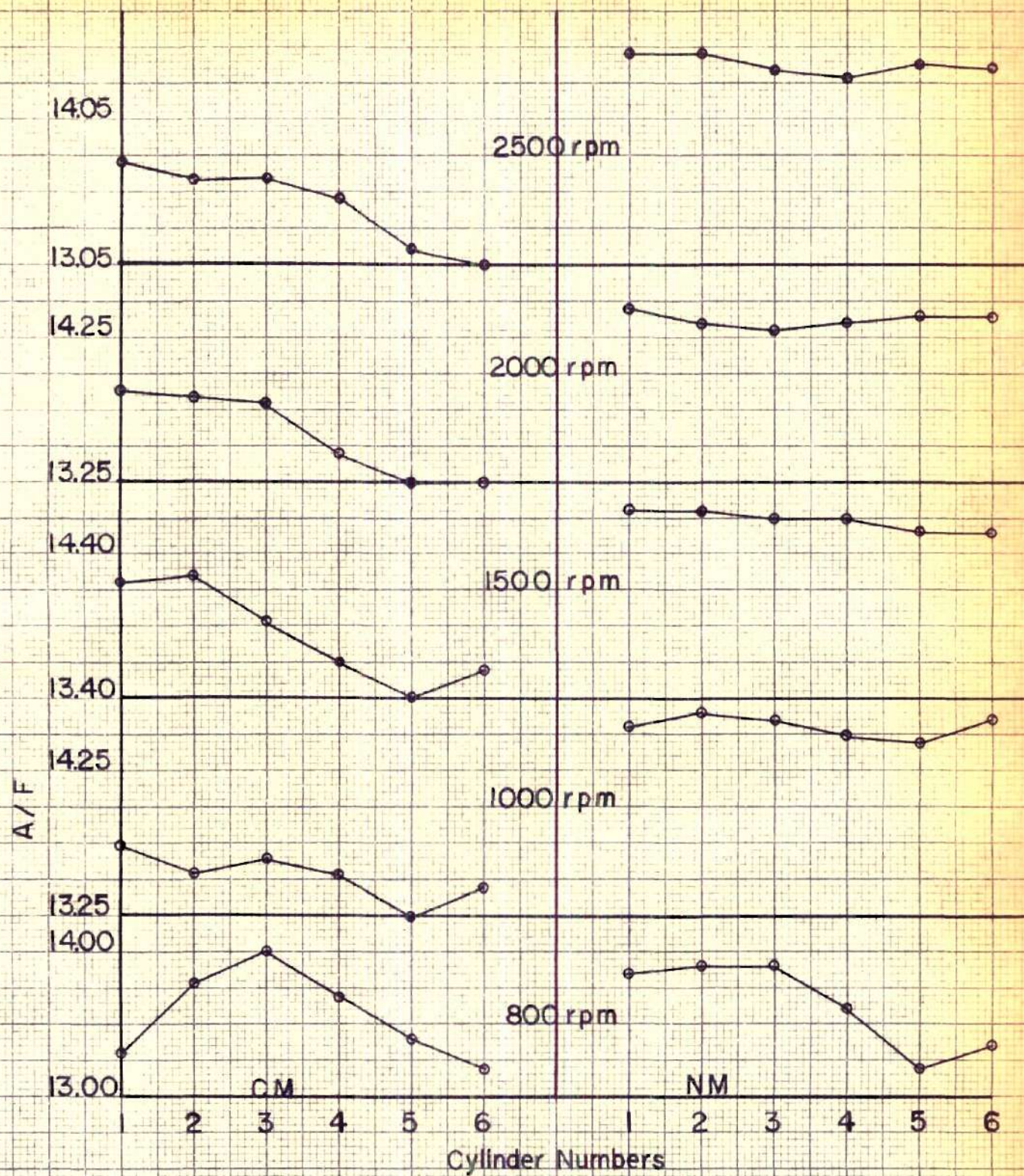


FIGURE 9
1/2 Throttle

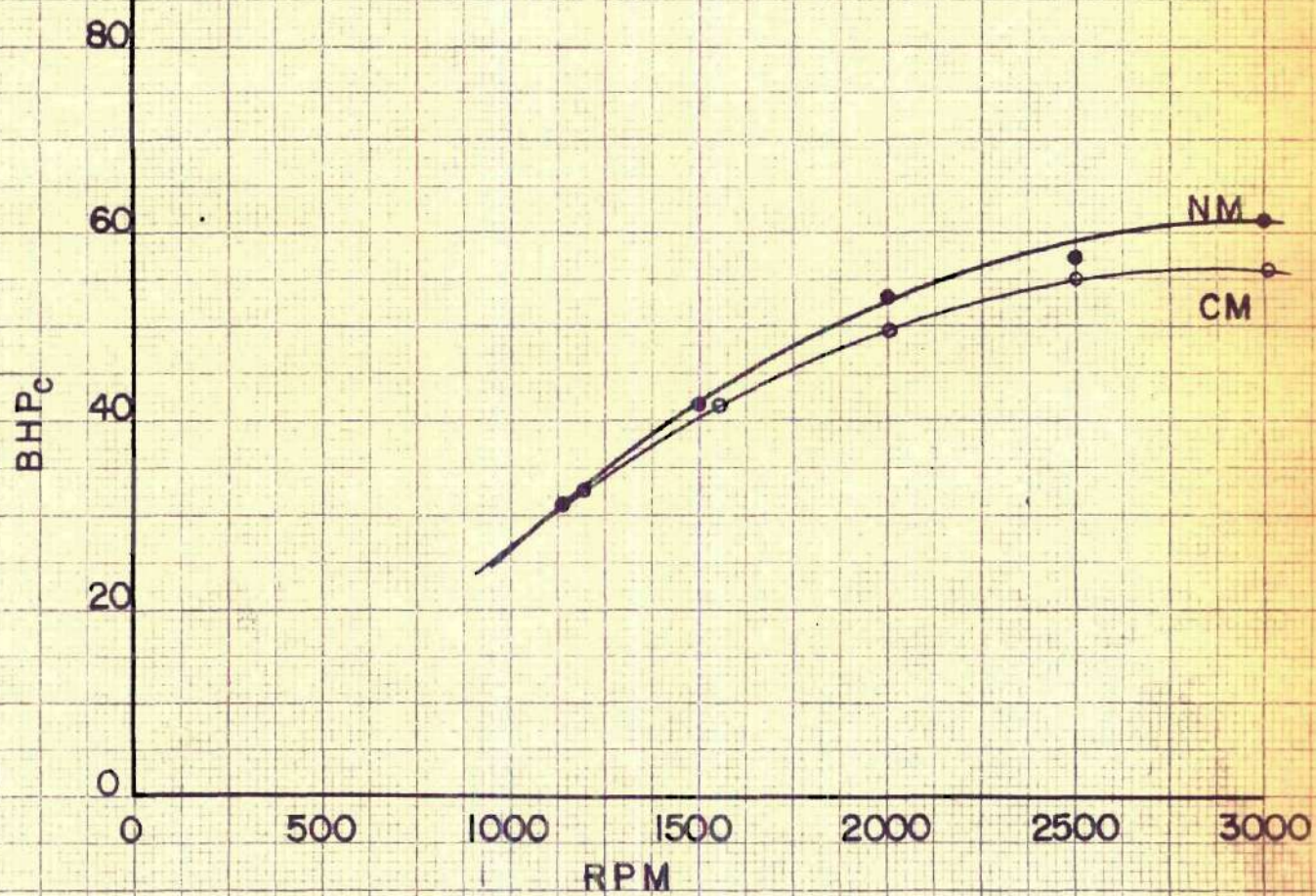


FIGURE 10
Full Throttle

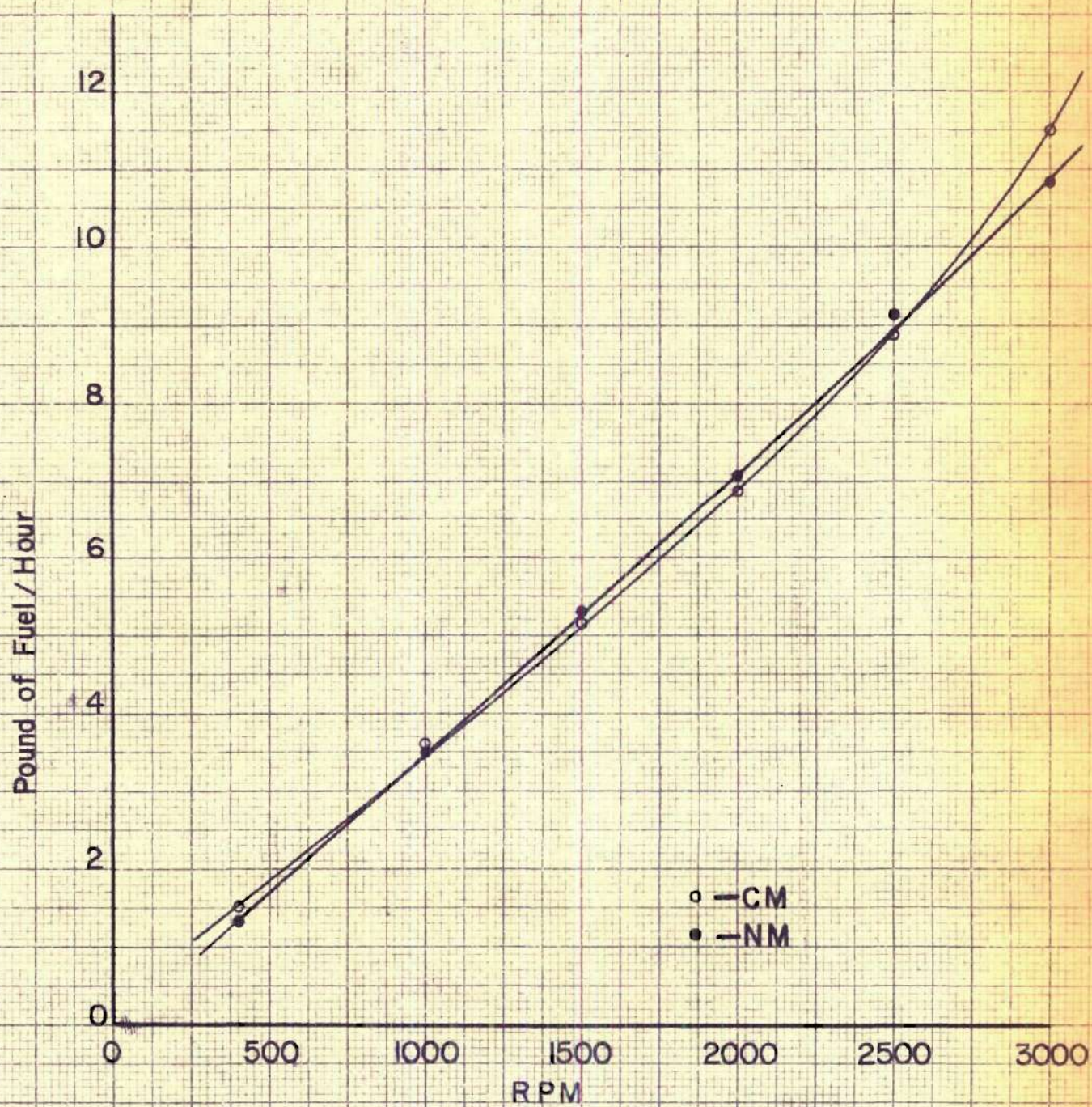


FIGURE II
No Load

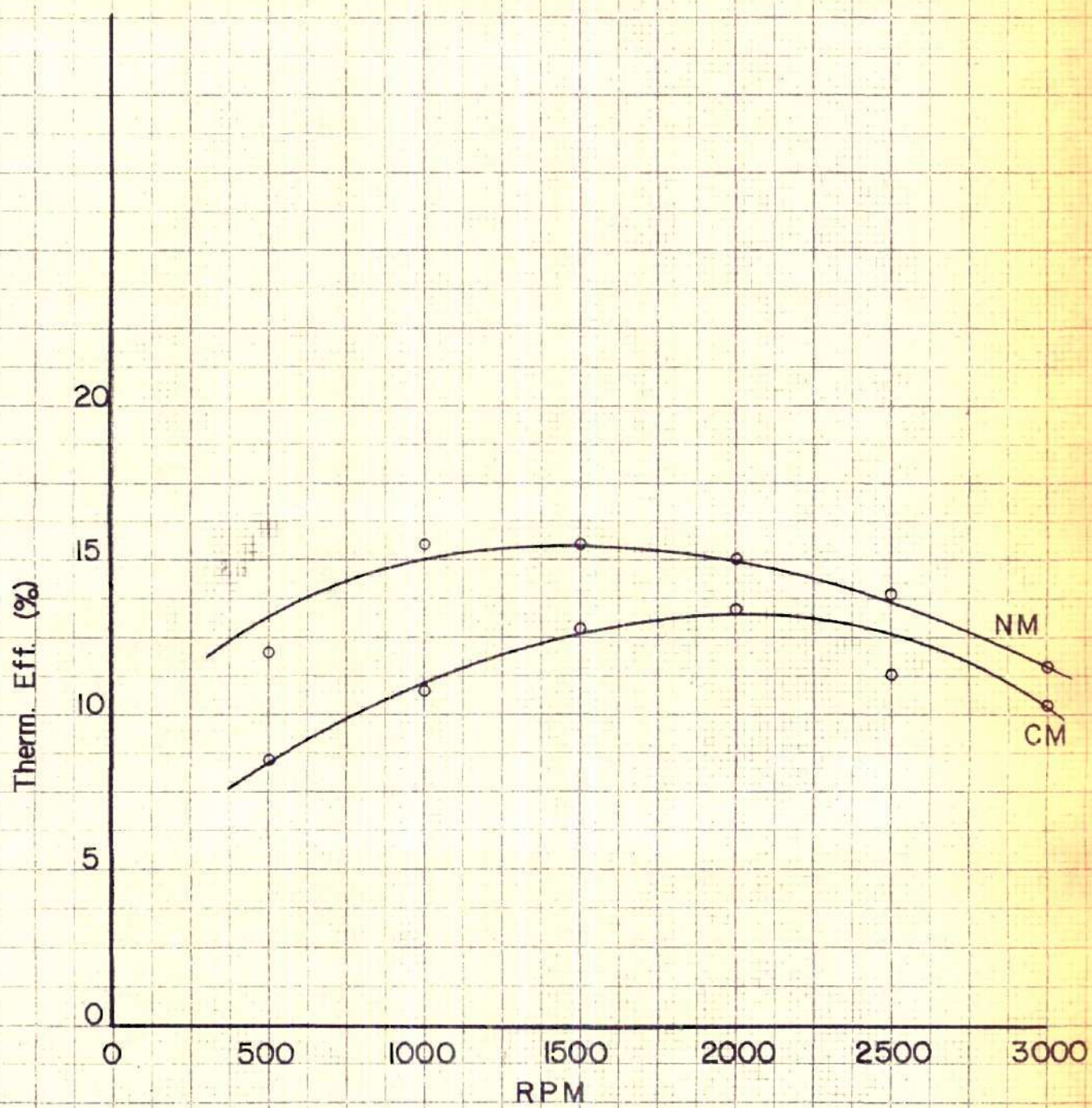


FIGURE 12
1/8 Throttle

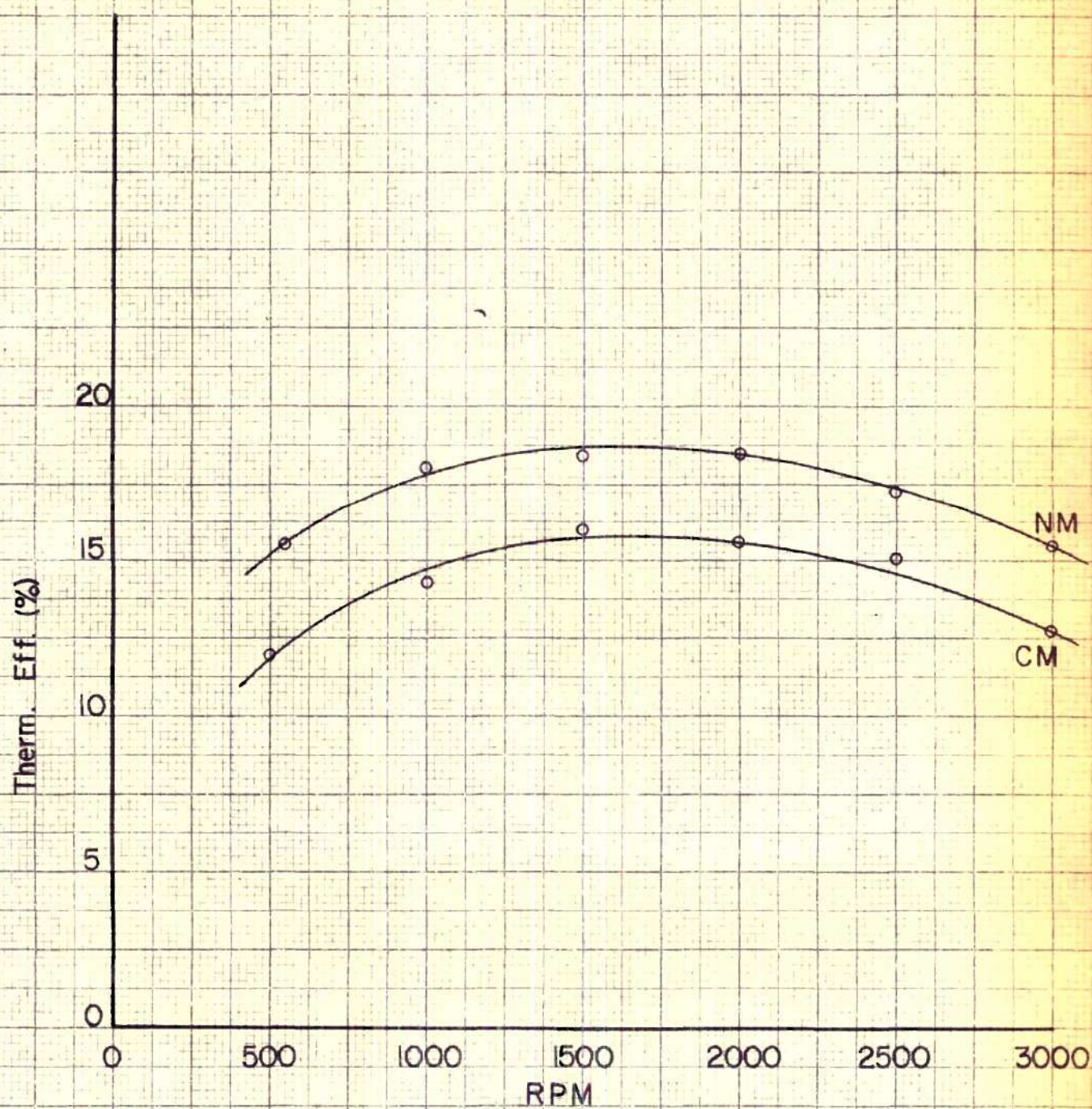


FIGURE 13
1/4 Throttle

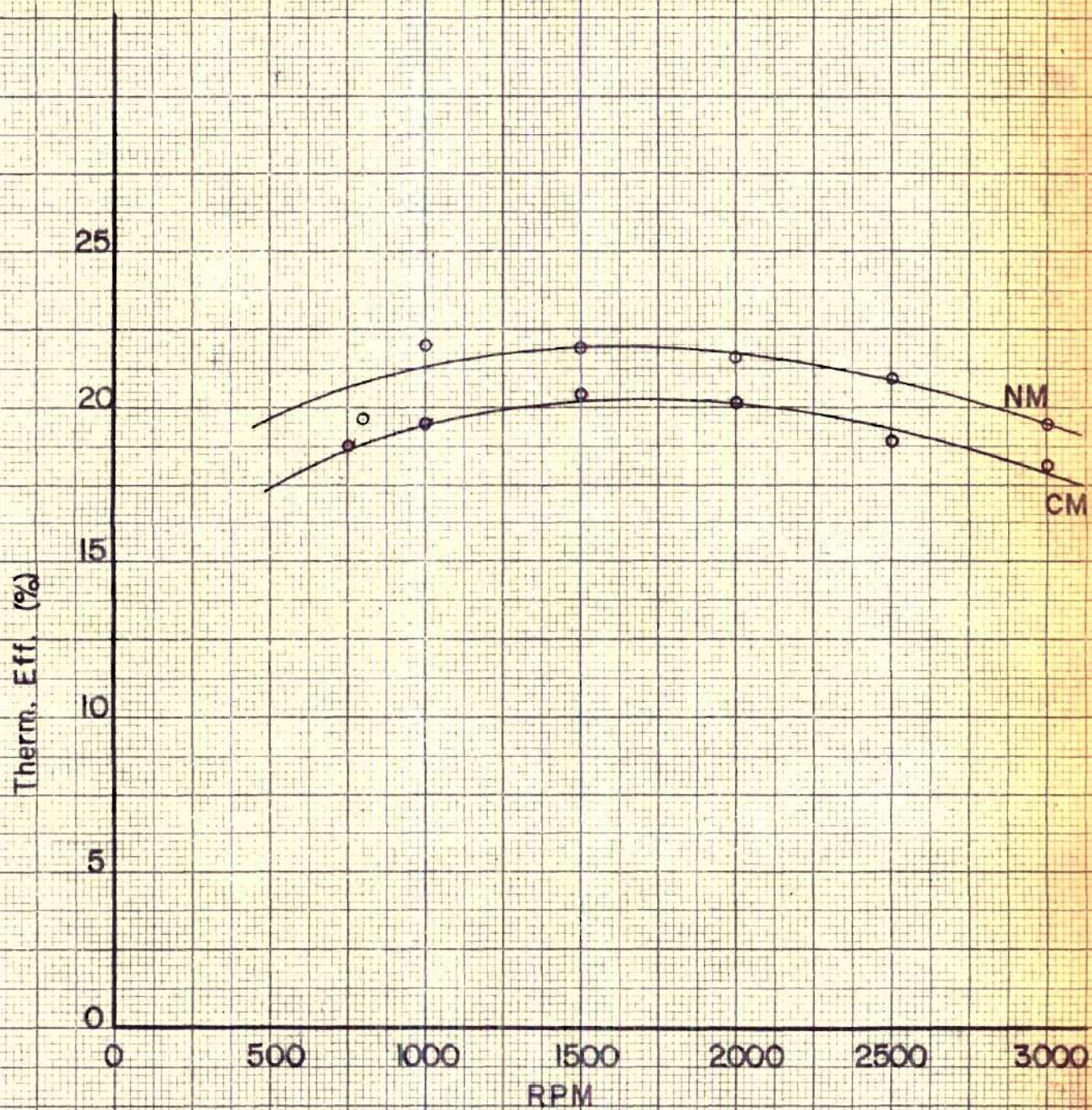


FIGURE 14
1/2 Throttle

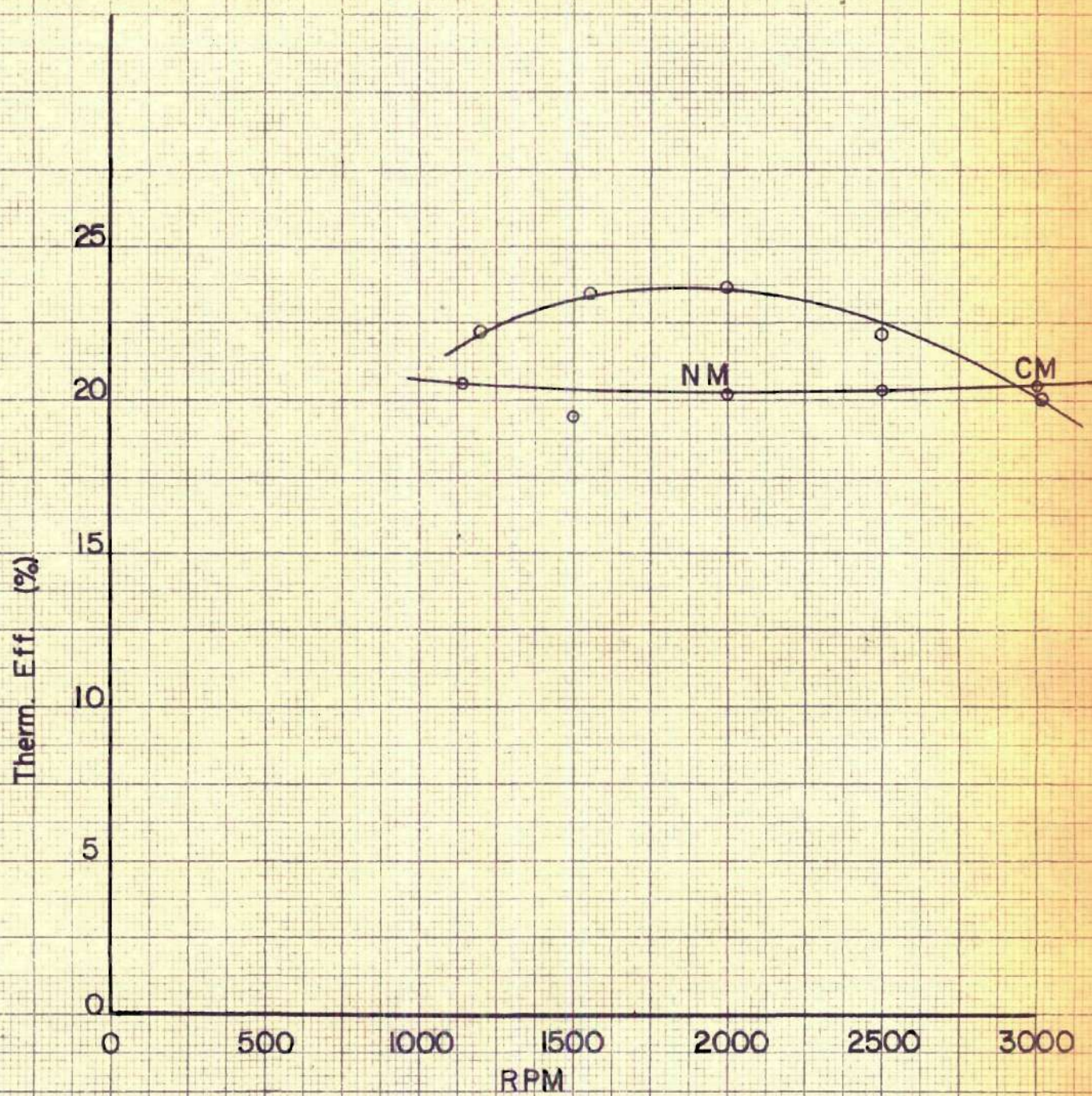


FIGURE 15
Full Throttle

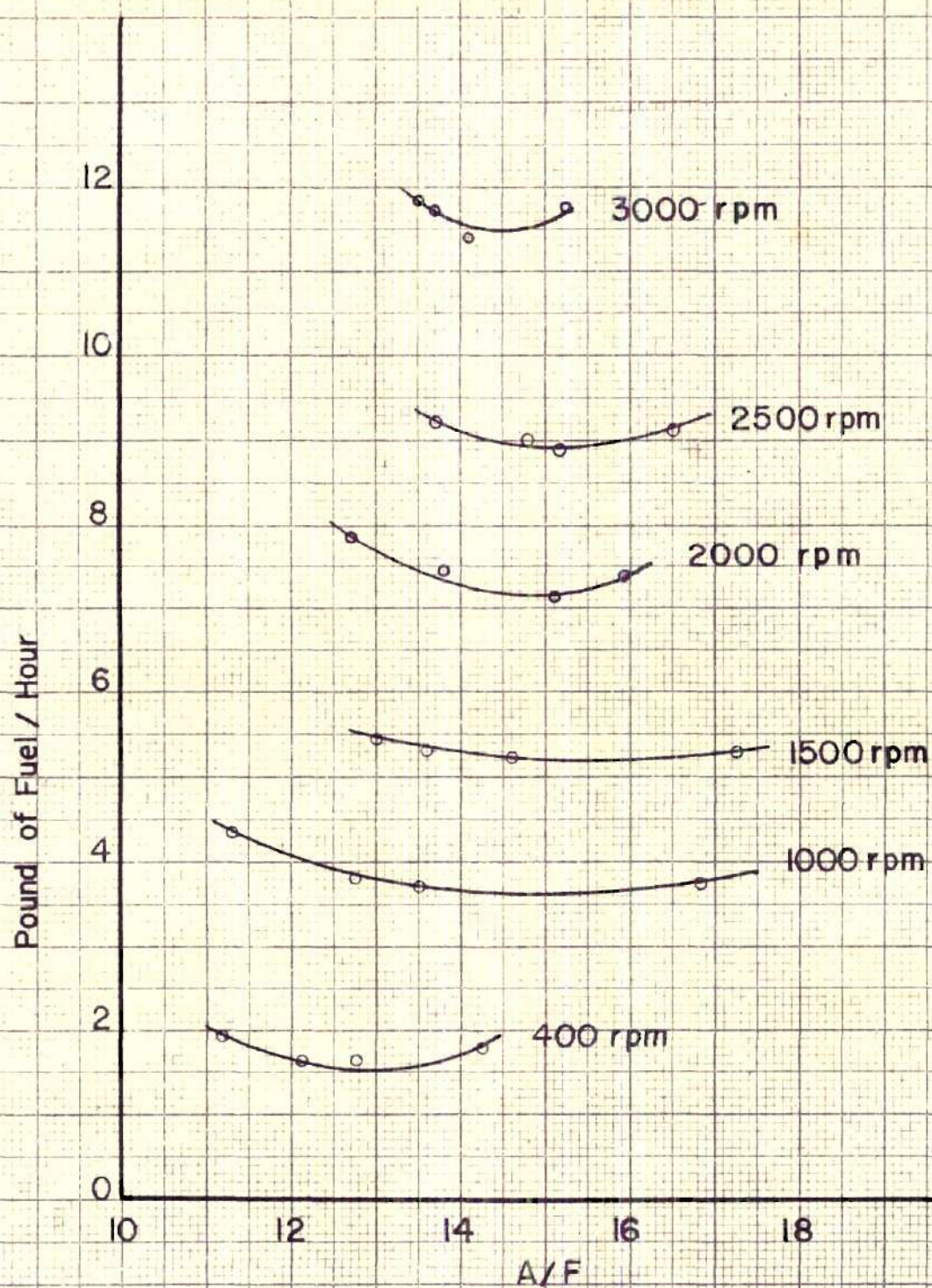


FIGURE 16
No Load
Conv. Manifold

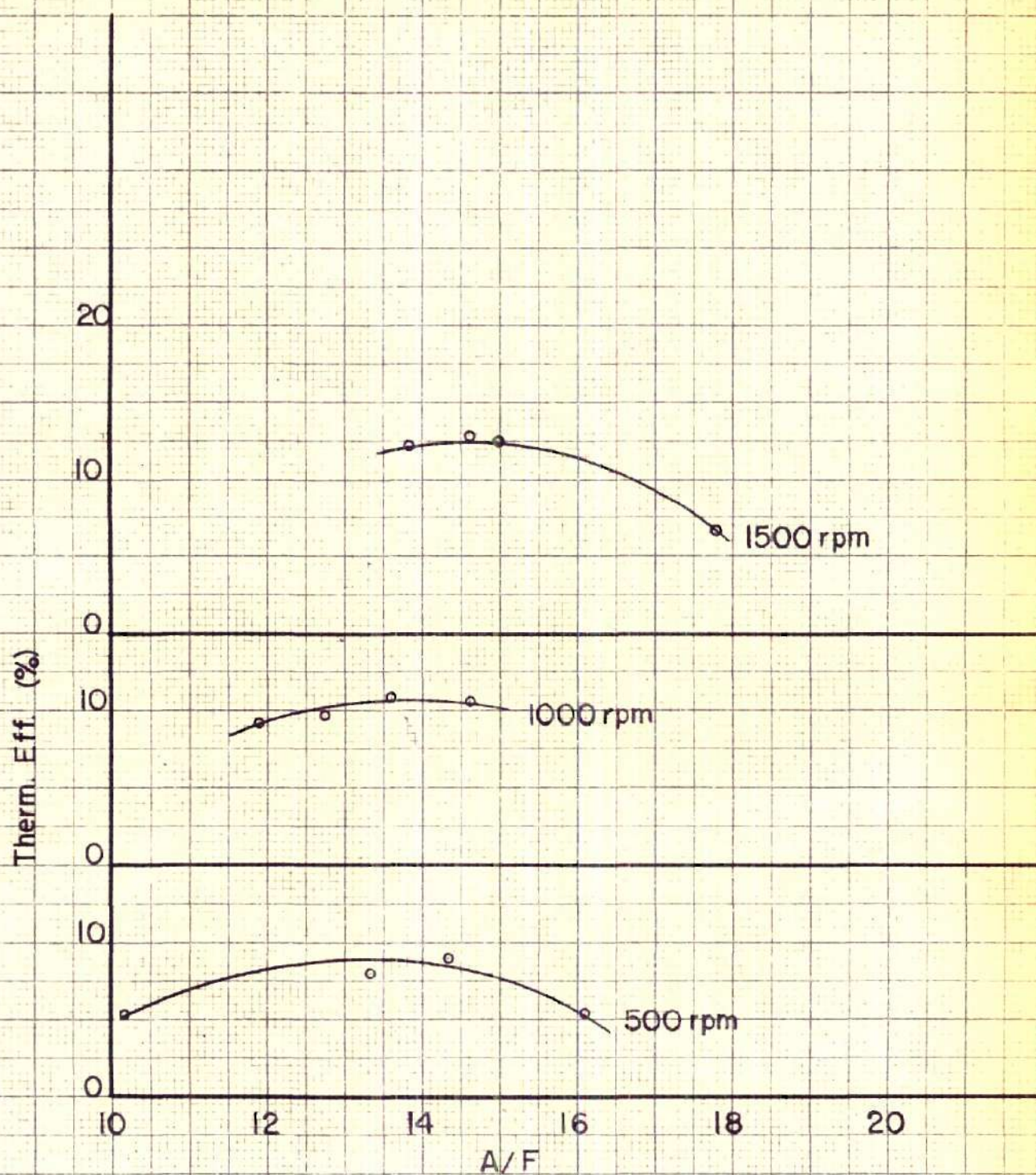


FIGURE 17
1/8 Throttle
Conv. Manifold

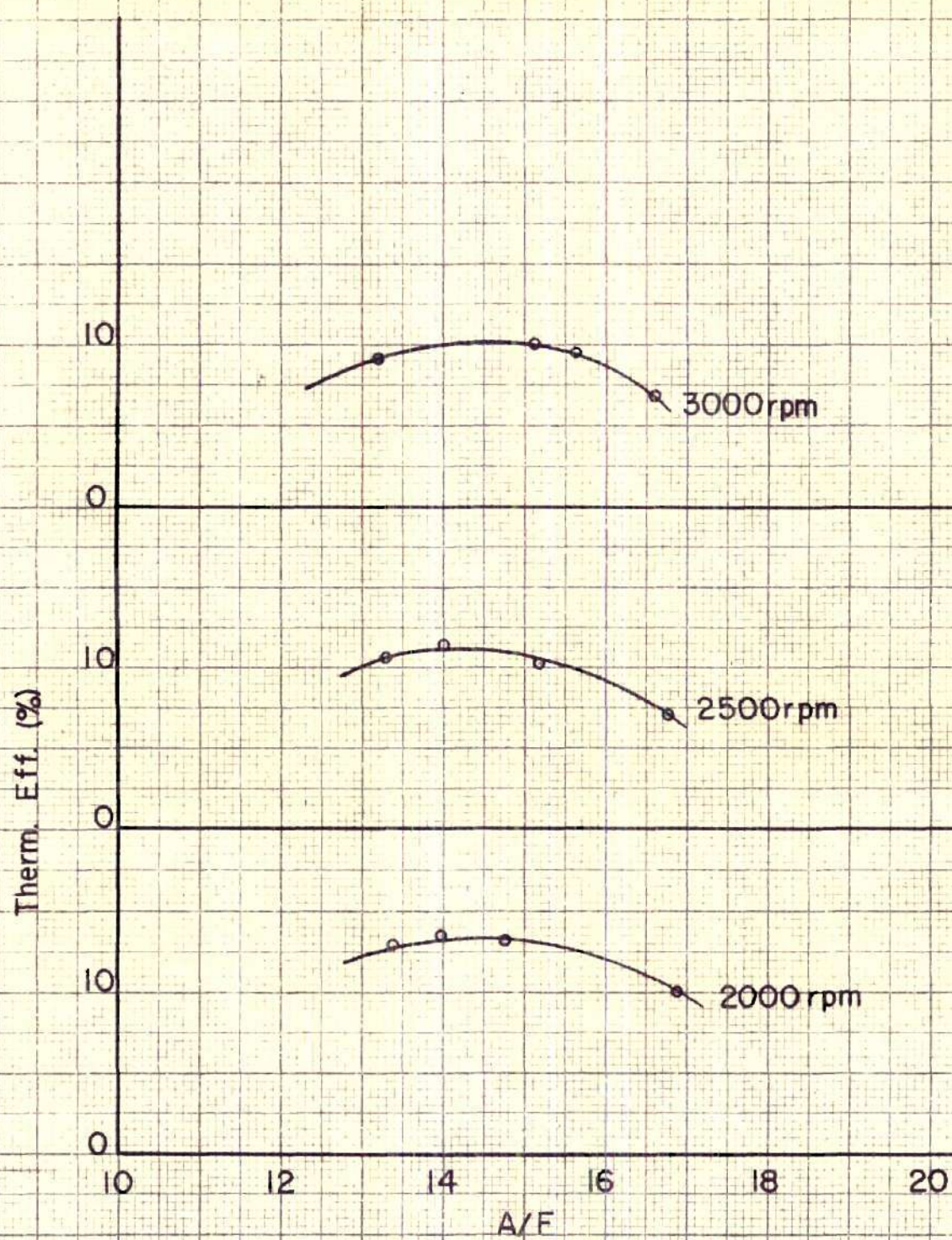


FIGURE 18
1/8 Throttle
Conv. Manifold

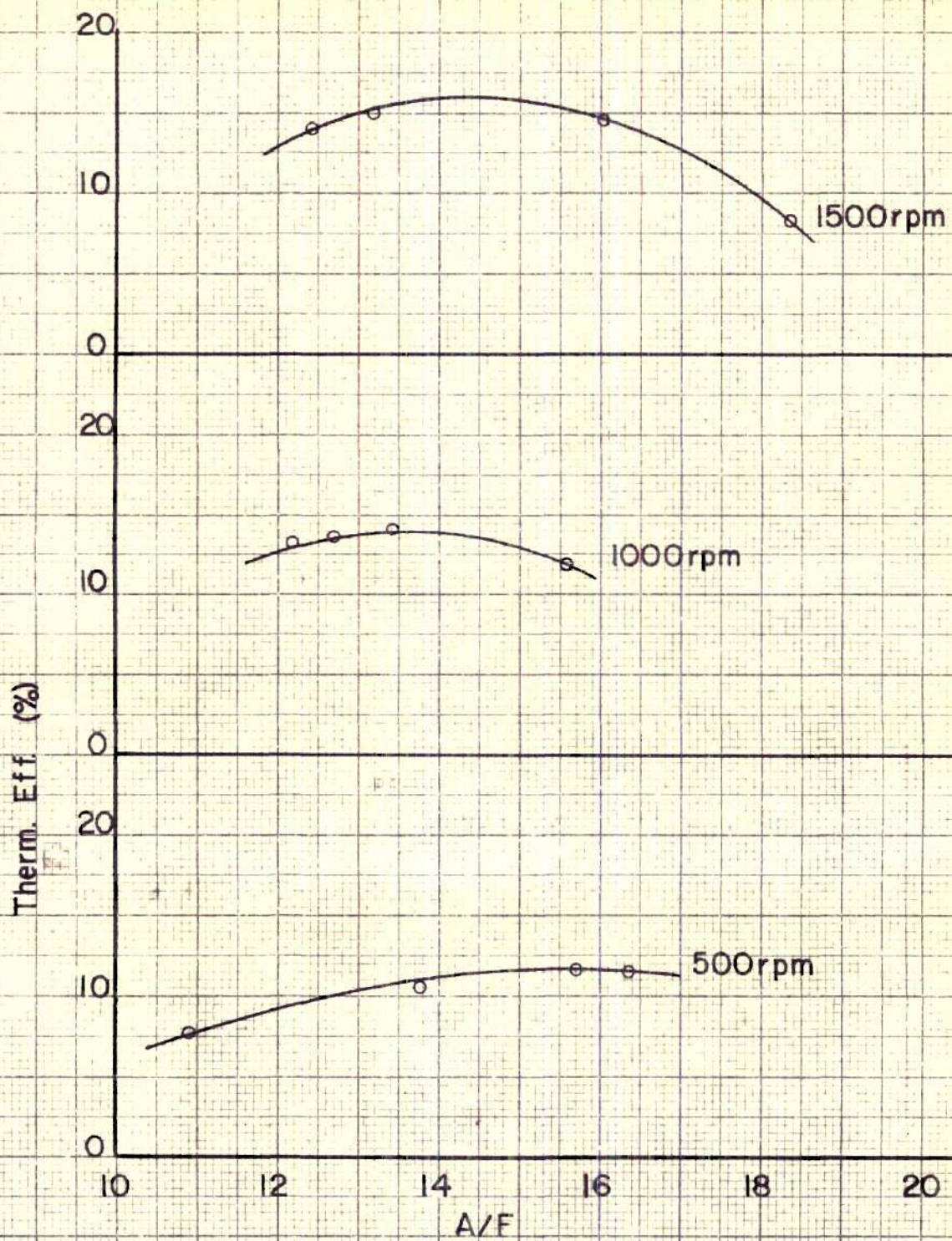


FIGURE 19
1/4 Throttle
Conv. Manifold

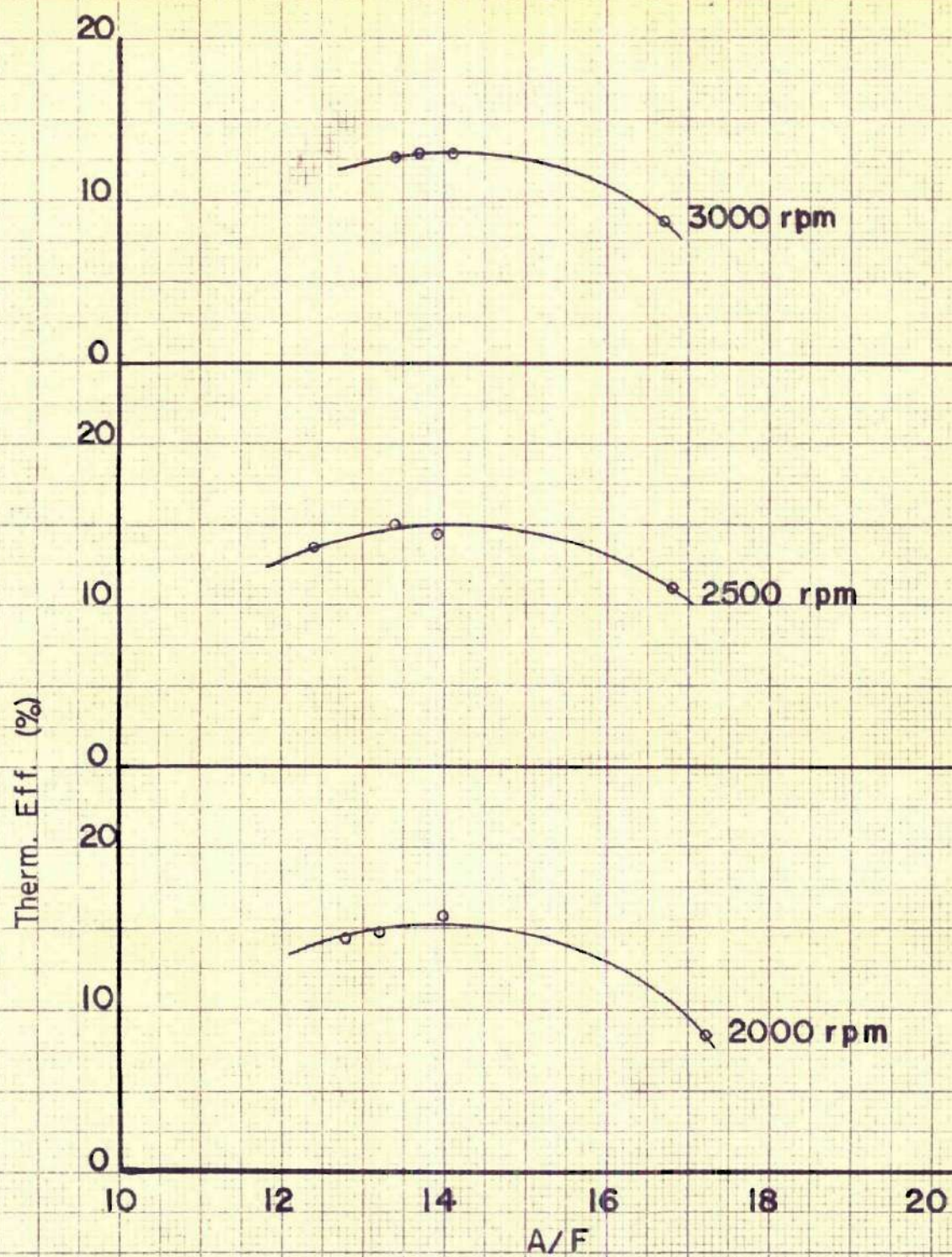


FIGURE 20
1/4 Throttle
Conv. Manifold

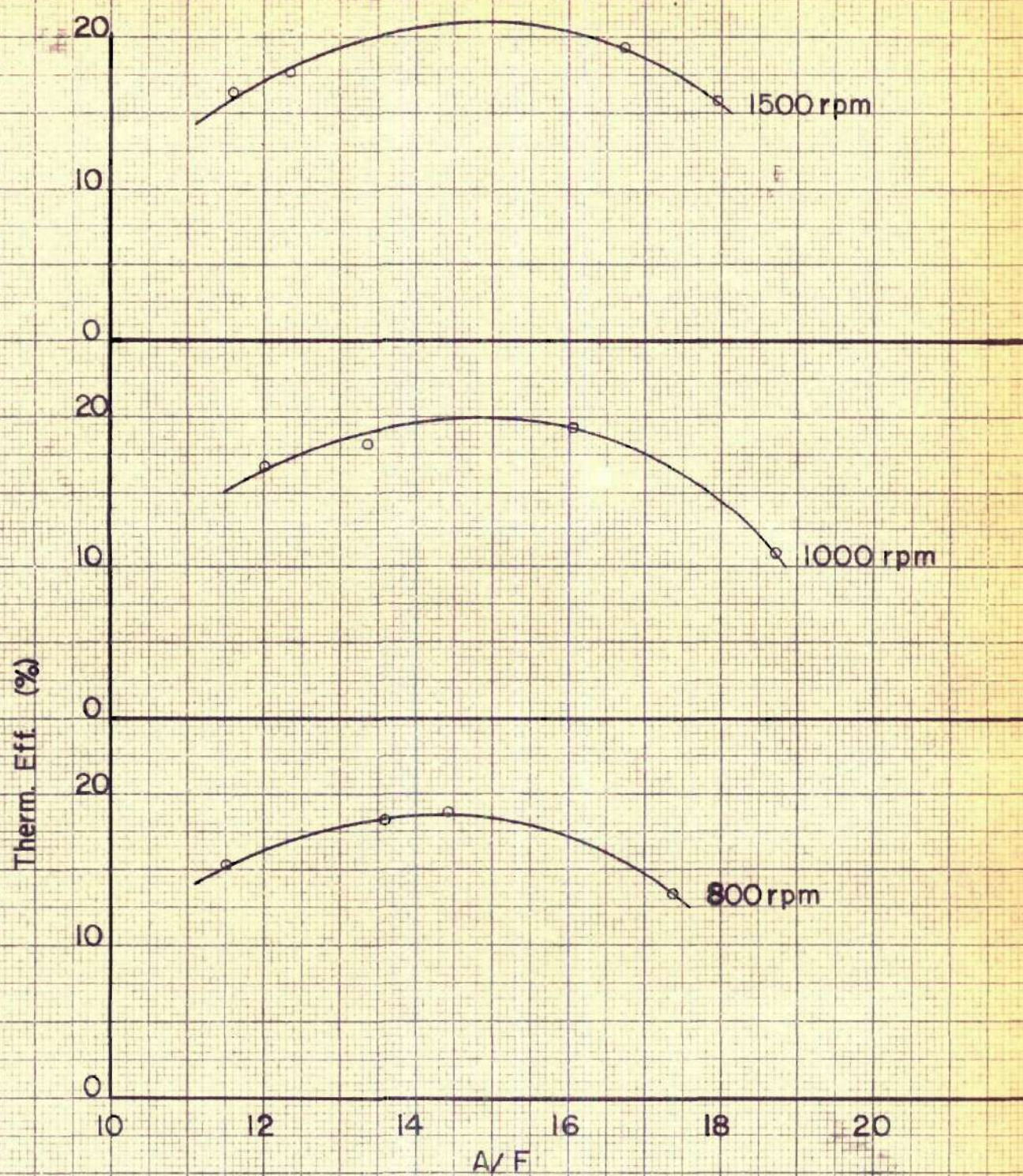


FIGURE 21
1/2 Throttle
Conv. Manifold

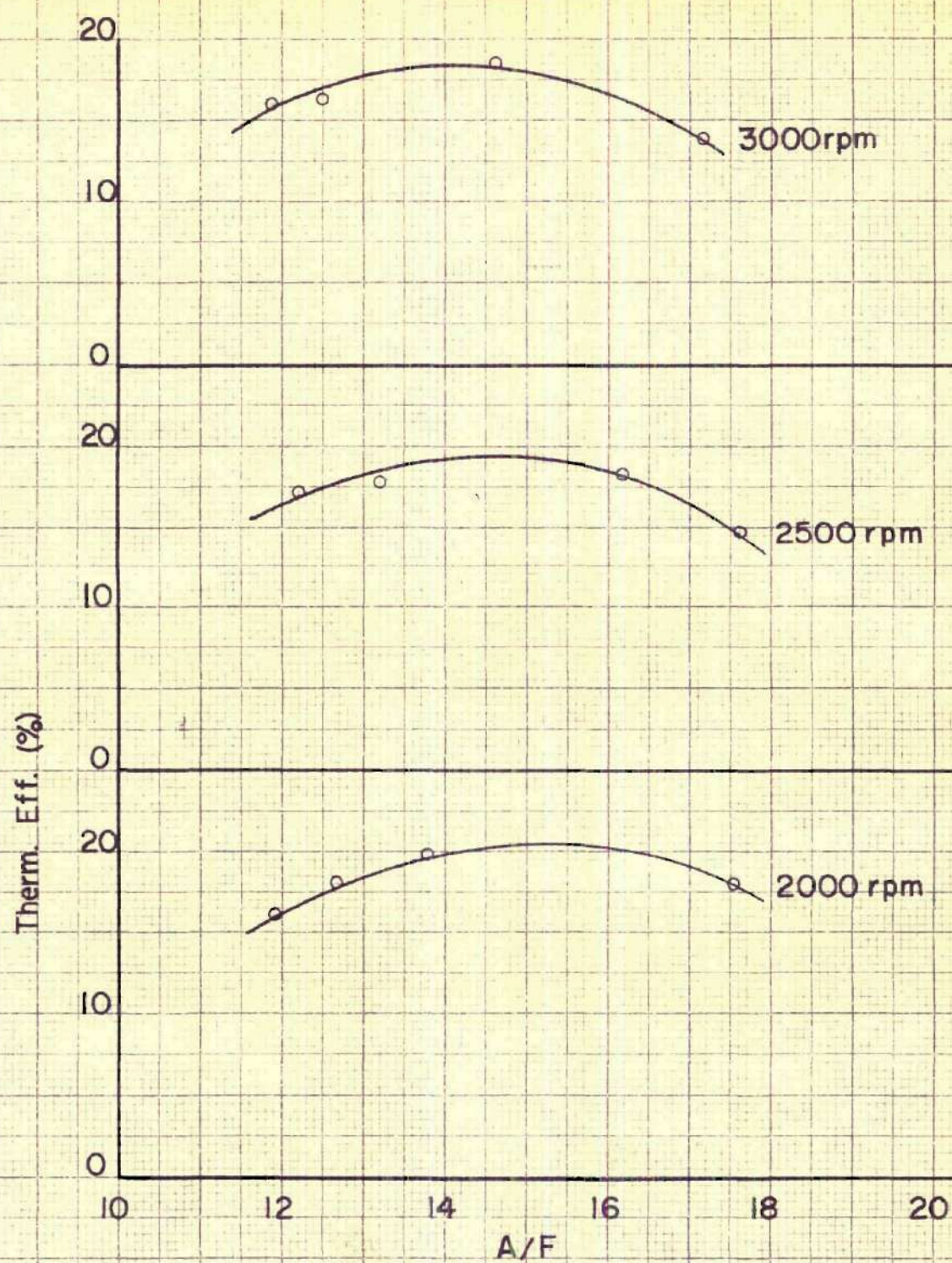


FIGURE 2 2
1/2 Throttle
Conv. Manifold

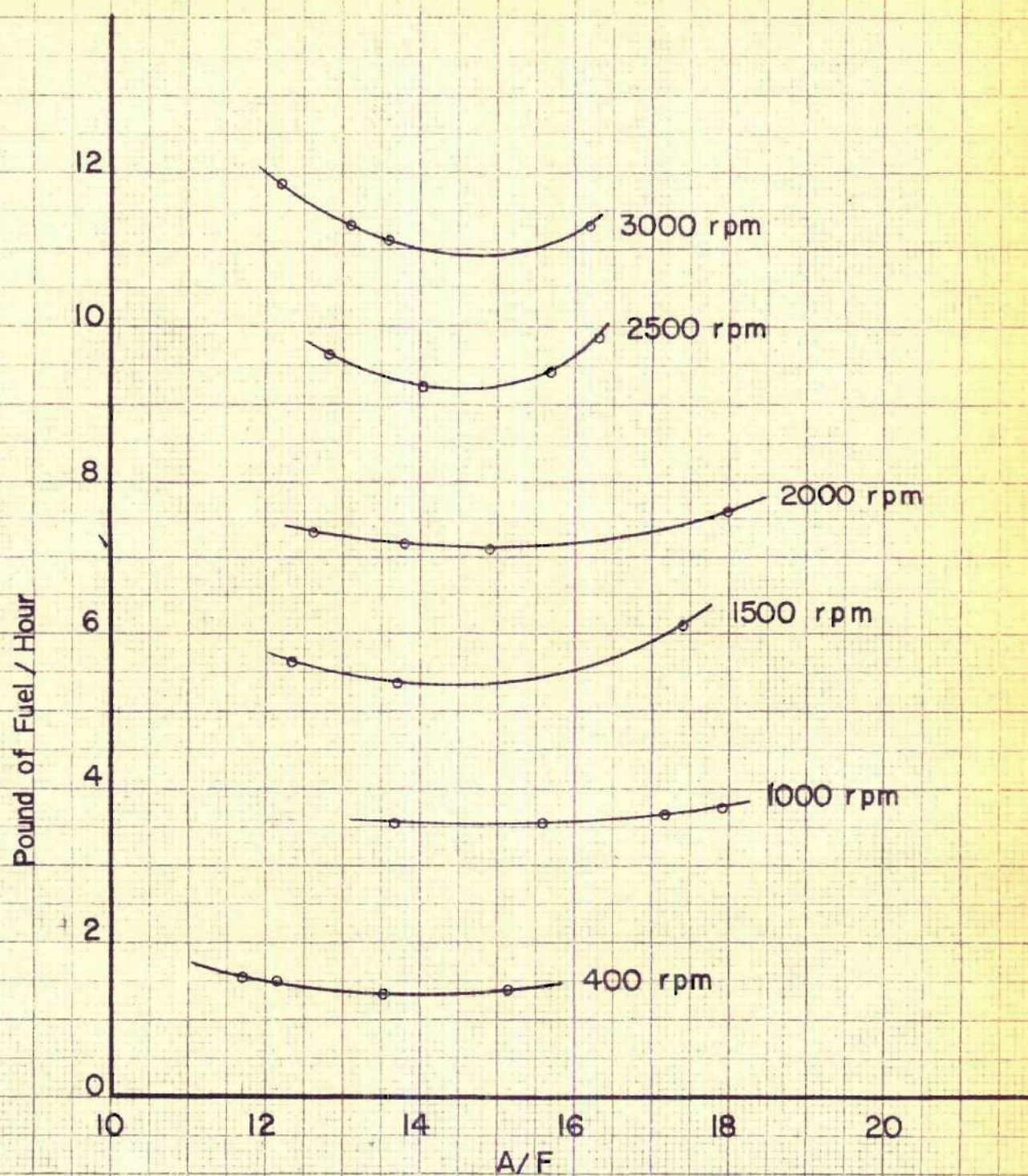


FIGURE 23
No Load
New Manifold

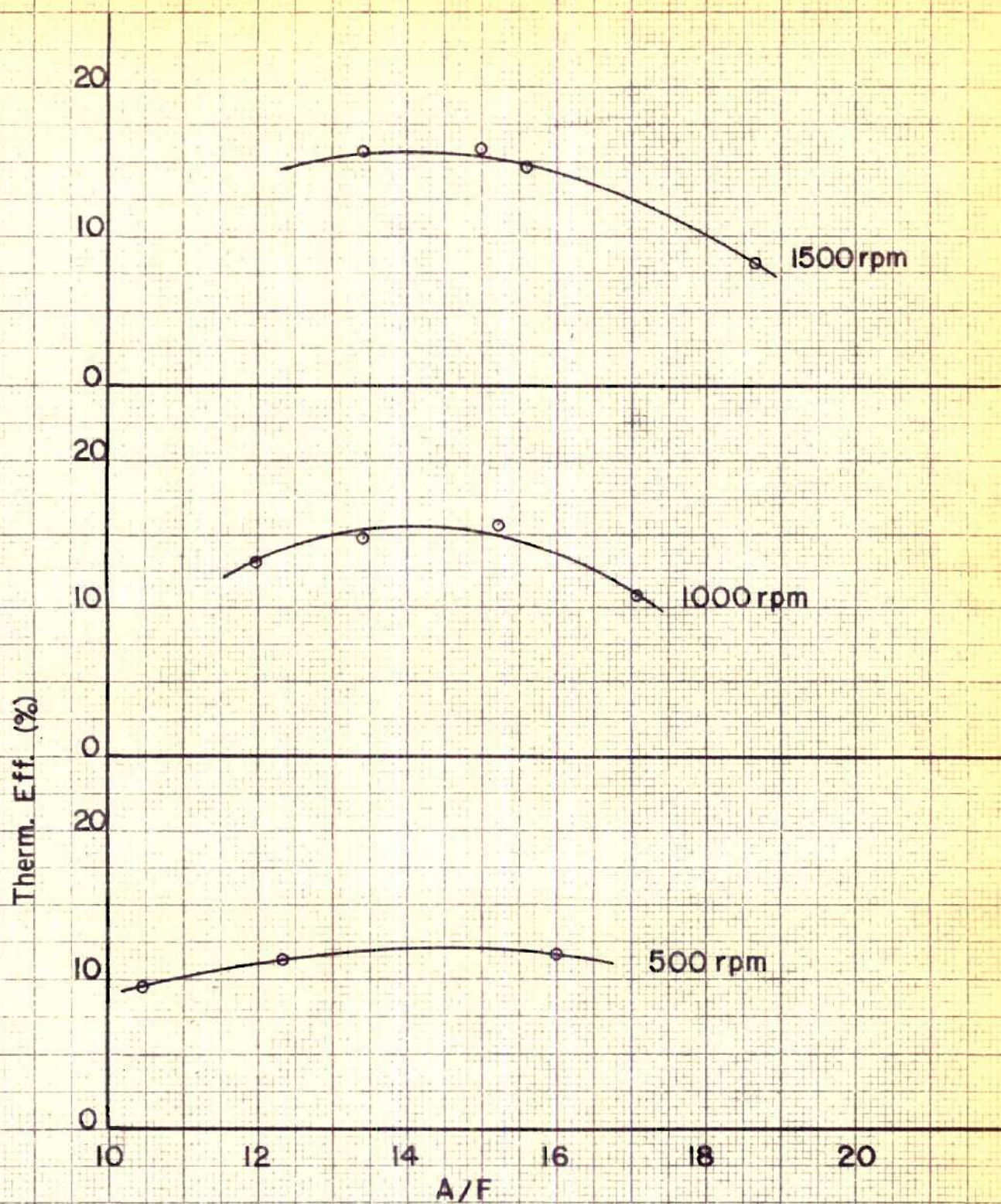


FIGURE 24
1/8 Throttle
New Manifold

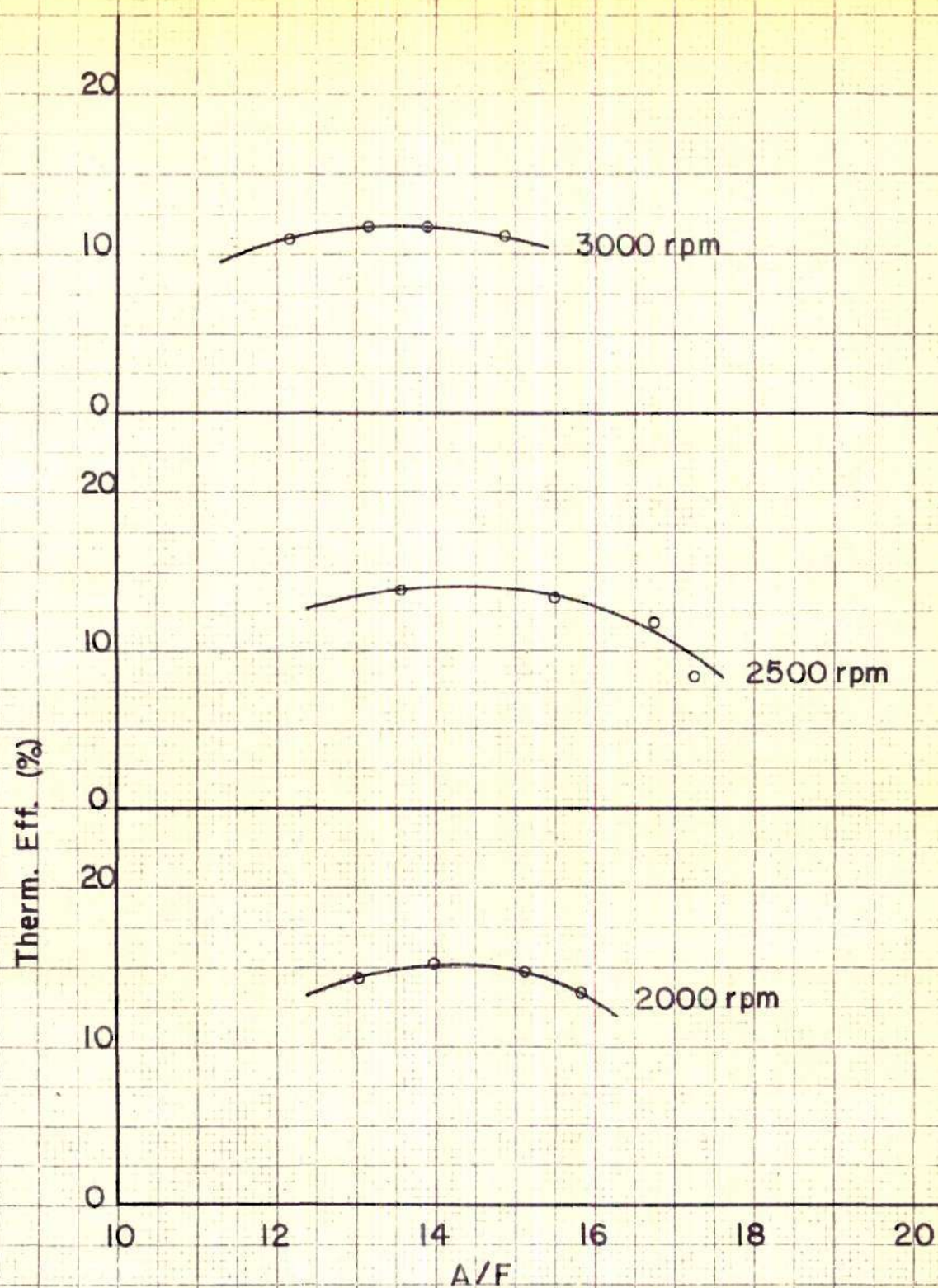


FIGURE 25
1/8 Throttle
New Manifold

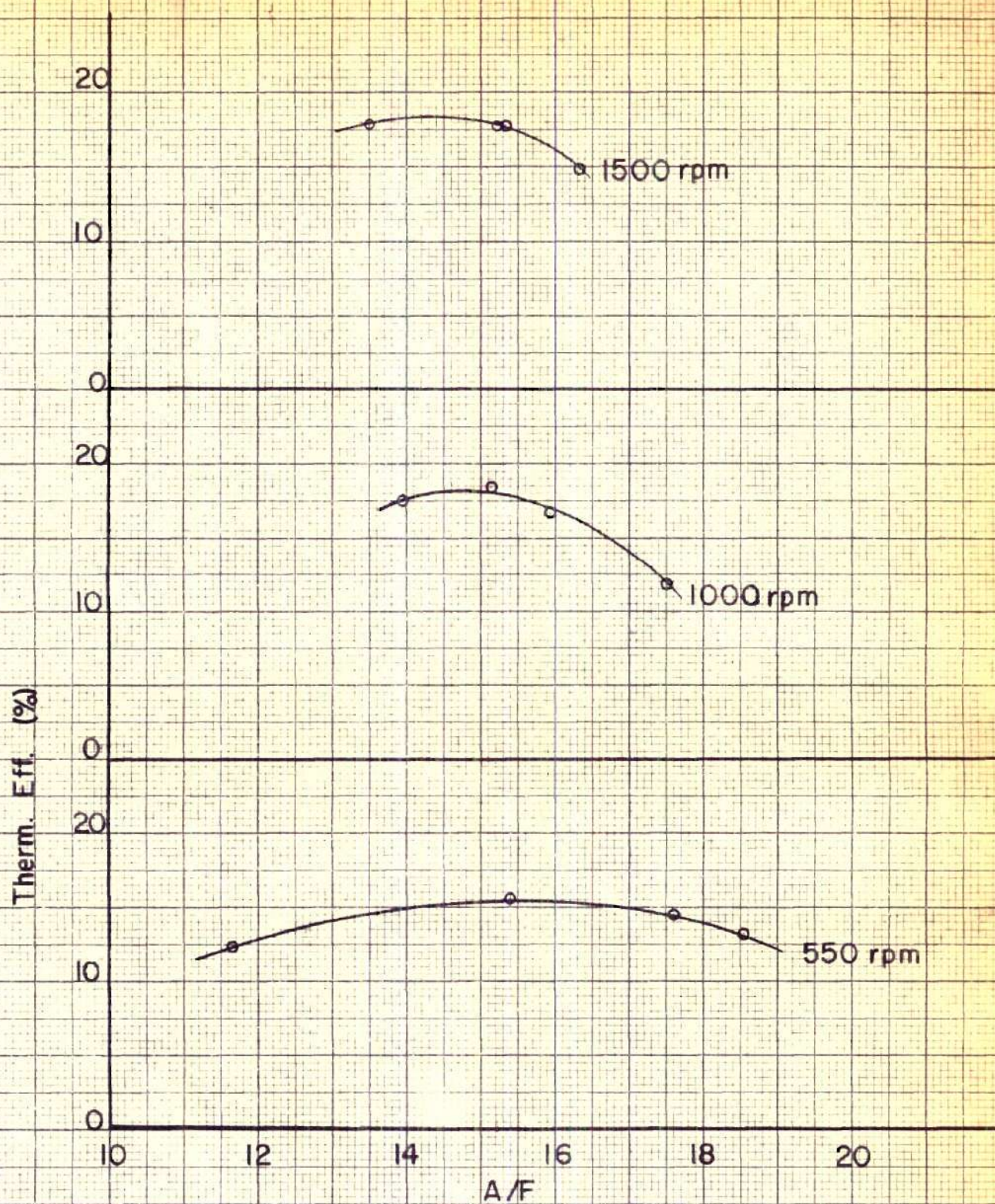


FIGURE 26
1/4 Throttle
New Manifold

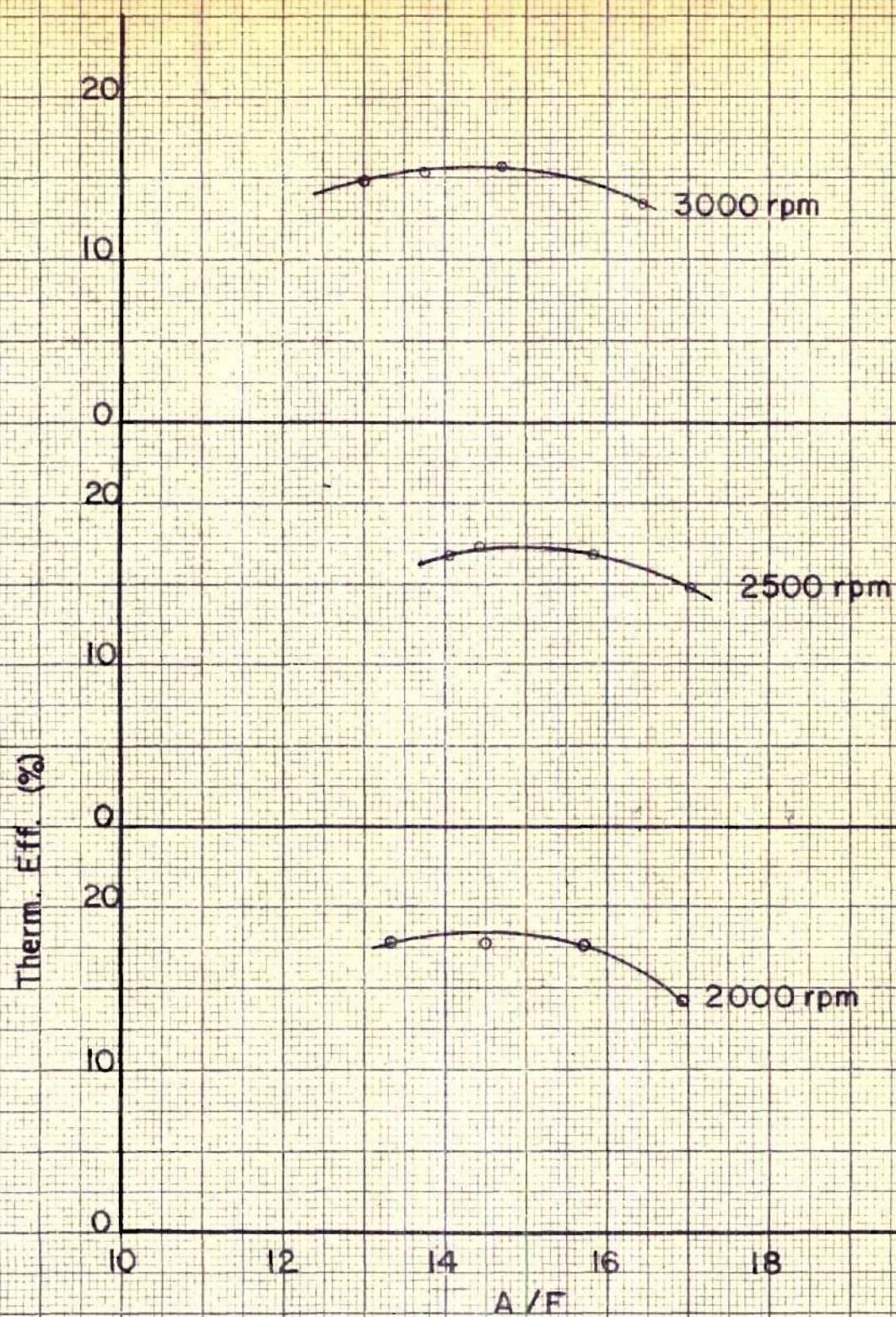


FIGURE 27
1/4 Throttle
New Manifold

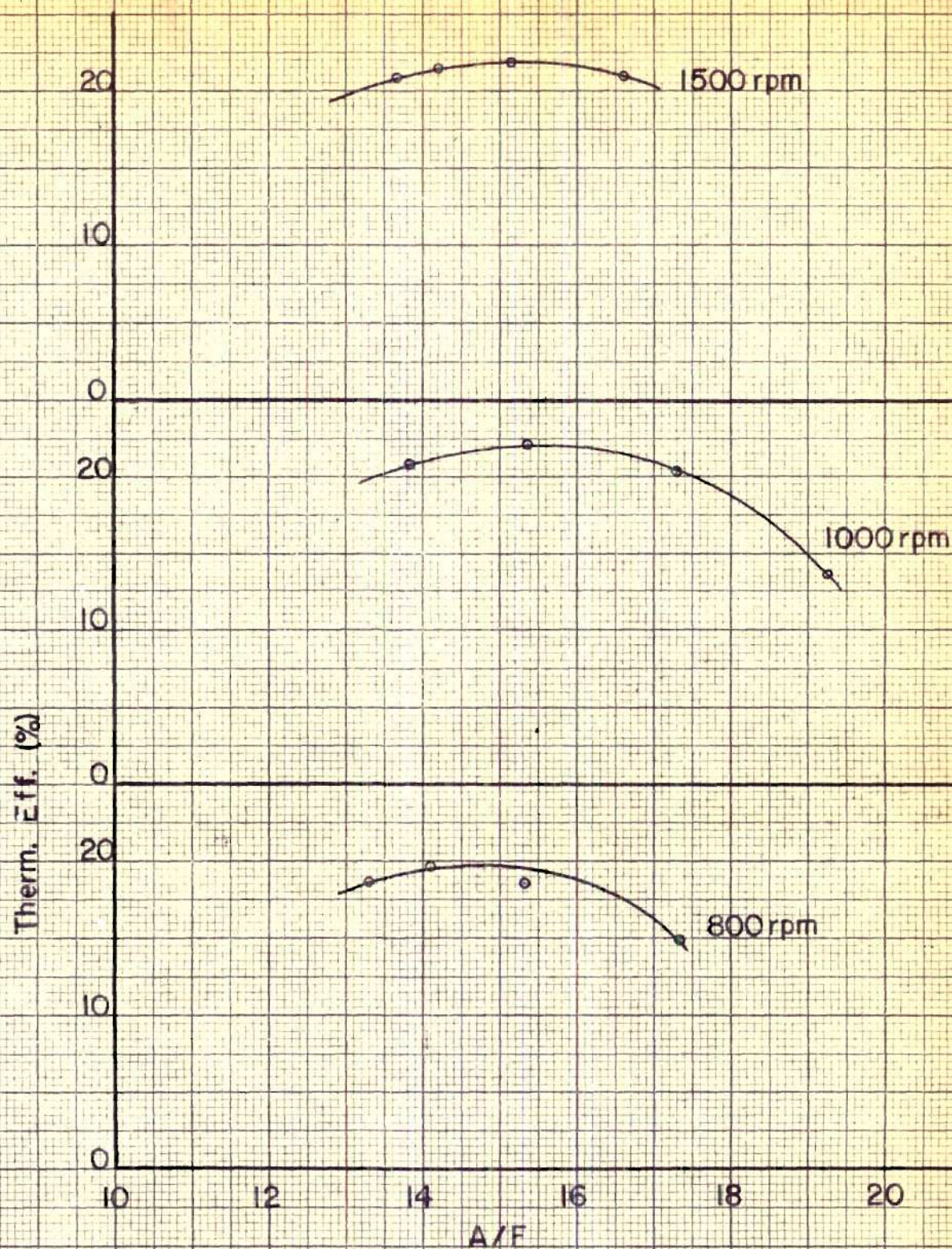


FIGURE 28
1/2 Throttle
New Manifold

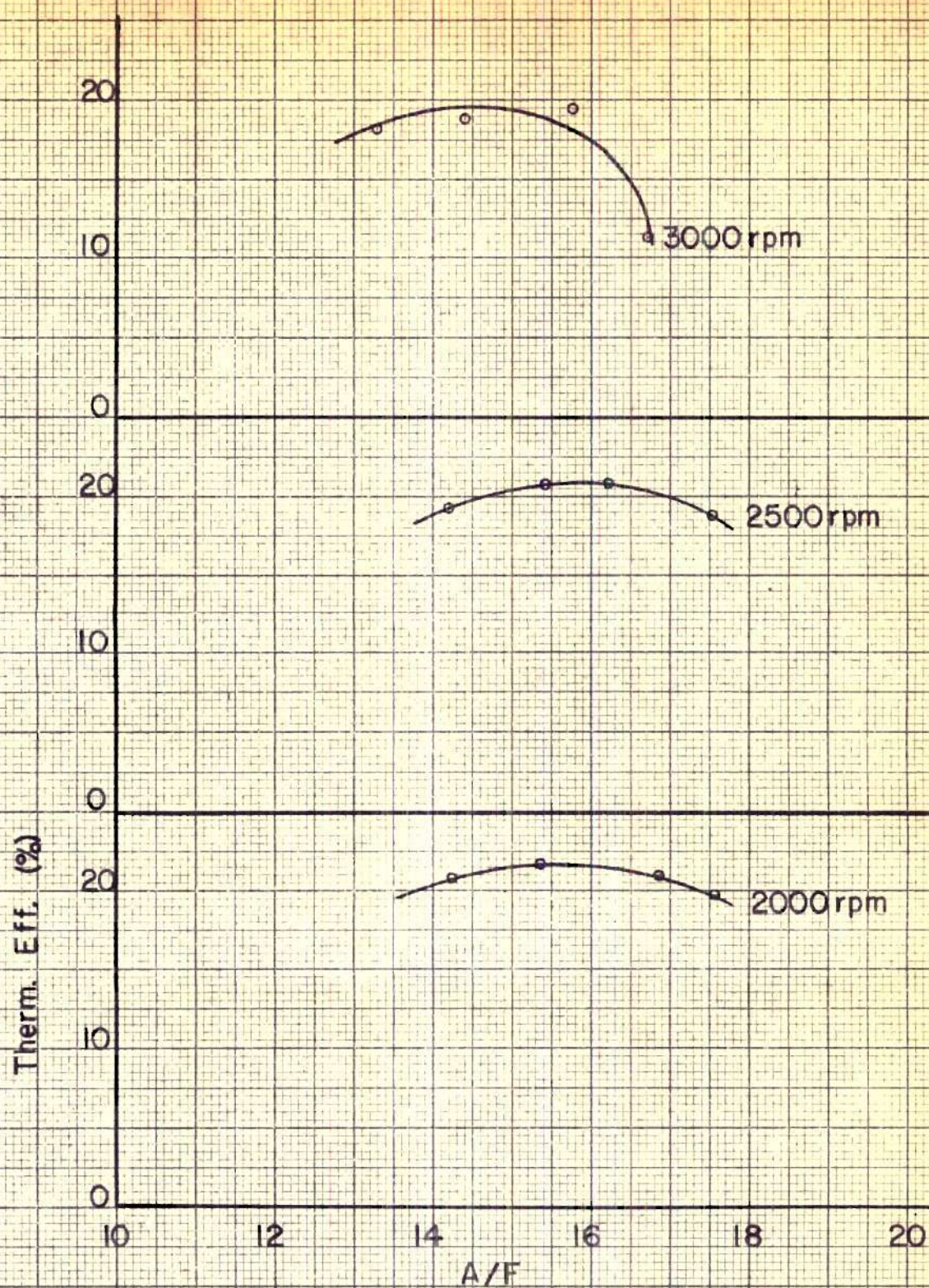


FIGURE 29
1/2 Throttle
New Manifold

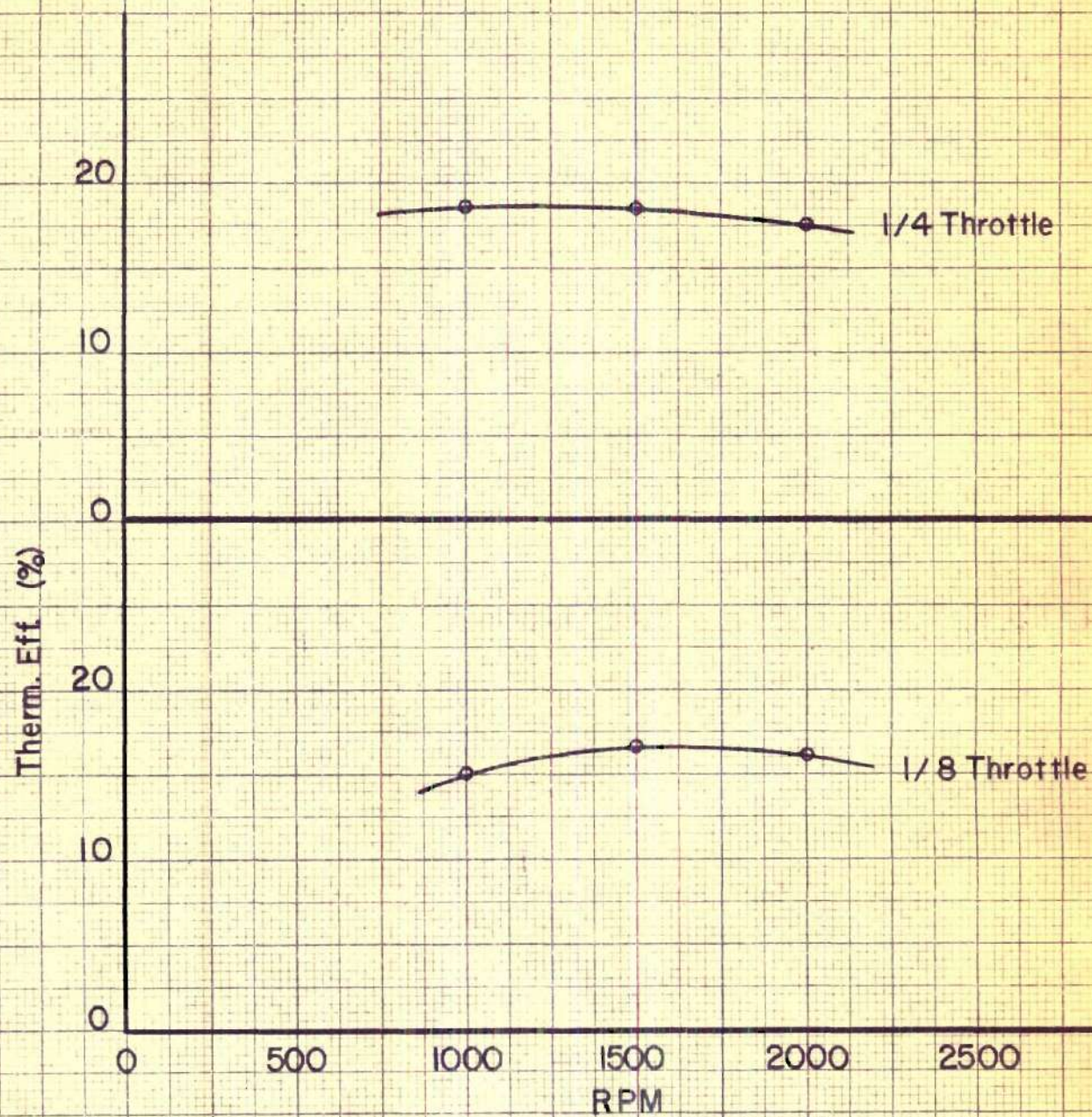


FIGURE 30
Conv. Manifold
Check Runs

APPENDIX II

TABLES

APPENDIX II

TABLE I OBSERVED DATA GROUP A NO LOAD

R _{un}	t	N	W _f	SA	L	WB	DB	BP
1	6.66	400	0.20	25	NL	78	93	28.94
2	7.29	400	0.20	25	NL	78	92	28.94
3	7.24	395	0.20	25	NL	78	92	28.94
4	9.07	400	0.30	25	NL	78	92	28.94
5	6.43	1000	0.40	39	NL	78	92	28.94
6	6.45	1005	0.40	39	NL	78	92	28.94
7	6.28	1000	0.40	39	NL	78	92	28.94
8	6.88	1000	0.50	39	NL	78	92	28.94
9	6.80	1500	0.60	50	NL	78	94	28.94
10	6.90	1500	0.60	50	NL	78	94	28.94
11	5.64	1500	0.50	50	NL	78	94	28.94
12	5.54	1500	0.50	50	NL	78	93	28.94
13	4.87	2000	0.60	50	NL	77	89	28.95
14	5.04	2000	0.60	50	NL	77	89	28.95
15	4.85	2000	0.60	50	NL	77	89	28.95
16	5.32	2000	0.70	50	NL	78	89	28.95
17	7.23	2500	1.10	50	NL	77	91	28.93
18	4.72	2500	0.70	50	NL	77	88	28.93
19	8.77	2500	1.30	50	NL	77	91	28.93
20	4.56	2500	0.70	50	NL	77	91	28.93
21	4.59	3000	0.90	50	NL	78	91	28.95
22	3.67	3000	0.70	50	NL	78	91	28.95
23	3.58	3000	0.70	50	NL	78	91	28.95
24	3.54	3000	0.70	50	NL	78	92	28.95

TABLE I OBSERVED DATA GROUP A (Continued) NO LOAD

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	12.50	0.205*	13.60	13.50	13.45	13.50	13.50	13.50
2	11.00	0.138*	12.82	13.10	13.10	13.15	13.25	13.20
3	11.00	0.124*	12.70	13.00	13.00	13.05	13.15	13.15
4	11.50	0.150*	12.30	12.82	12.80	12.90	12.95	12.95
5	10.90	1.228*	13.82	13.60	13.70	13.75	13.65	13.80
6	9.50	0.784*	13.25	13.22	13.20	13.10	13.15	13.10
7	9.00	0.737*	12.95	13.05	12.95	12.95	13.02	12.85
8	9.50	0.754*	12.55	12.85	12.70	12.70	12.85	12.40
9	9.90	2.564*	14.00	13.70	13.80	13.85	13.82	14.00
10	8.50	1.818*	13.65	13.45	13.40	13.30	13.30	13.35
11	8.00	1.650*	13.30	13.25	13.10	12.95	13.05	13.05
12	8.00	1.560*	12.90	13.00	12.90	12.80	12.85	12.25
13	9.00	4.300*	14.50	14.30	13.25	13.90	14.15	14.35
14	8.00	3.600*	13.95	13.95	13.85	13.85	13.80	13.75
15	8.00	3.400*	13.40	13.40	13.35	13.40	13.35	13.25
16	8.00	3.100*	12.25	12.35	12.35	12.90	12.20	12.20
17	9.80	7.100*	14.60	14.50	14.45	14.40	14.45	14.50
18	9.00	5.650*	14.00	14.00	14.00	13.90	13.95	13.90
19	9.00	5.400*	13.85	13.85	13.90	13.80	13.65	13.70
20	8.50	5.000*	13.15	13.20	13.25	13.15	12.95	13.90
21	9.70	10.000*	14.10	14.10	14.30	14.30	14.00	13.95
22	9.00	8.100*	13.30	13.20	13.40	13.45	13.25	13.20
23	9.00	9.000*	12.90	12.95	12.95	13.30	12.95	12.95
24	8.80	7.800*	12.60	12.55	12.65	12.75	12.45	12.50

* All numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE I OBSERVED DATA GROUP A (Continued) 1/8 THROTTLE

Run	t	N	W _f	SA	L	WB	DB	BP
1	8.47	485	0.30	29	7.50	80	95	29.03
2	7.42	500	0.30	29	13.20	80	95	29.03
3	7.36	510	0.32	29	13.40	80	95	29.03
4	6.91	515	0.40	29	11.65	80	95	29.03
5	6.88	1005	0.60	30	17.90	80	95	29.03
6	6.40	1012	0.60	30	19.20	80	95	29.03
7	5.02	1012	0.50	30	18.70	80	95	29.03
8	5.64	1010	0.60	30	18.70	80	95	29.03
9	6.27	1495	0.70	37	9.90	82	94	29.03
10	6.37	1510	0.90	37	21.00	82	95	29.03
11	6.74	1500	0.90	37	22.05	83	96	29.03
12	5.74	1507	0.80	37	21.70	83	96	29.03
13	6.06	2000	0.90	50	14.50	82	94	29.07
14	5.32	2000	0.90	50	21.60	82	94	29.07
15	4.47	1990	0.80	50	23.30	82	94	29.07
16	5.35	2000	1.00	50	23.20	82	94	29.07
17	9.07	2495	1.70	50	10.10	83	94	29.07
18	4.52	2507	0.90	50	15.90	83	94	29.07
19	4.70	2495	1.00	50	18.70	83	94	29.07
20	4.47	2510	1.00	50	18.50	83	94	29.07
21	5.40	3010	1.20	50	9.65	78	91	29.07
22	3.39	2995	0.80	50	15.00	78	91	29.07
23	3.68	3010	0.90	50	15.60	78	92	29.07
24	4.06	3015	1.10	50	16.00	78	92	29.07

TABLE I OBSERVED DATA GROUP A (Continued) 1/8 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	12.30	0.366*	13.60	13.50	13.45	13.50	13.45	13.45
2	12.30	0.378*	13.40	13.42	13.37	13.40	13.36	13.33
3	12.30	0.378*	13.10	13.22	13.30	13.30	13.25	13.20
4	12.30	0.391*	12.10	12.50	12.75	12.85	12.95	12.75
5	12.30	1.839*	13.85	13.58	13.45	13.36	13.40	13.35
6	12.30	1.842*	13.60	13.45	13.30	13.00	12.95	12.80
7	12.30	1.818*	13.15	13.25	13.10	12.75	12.75	12.10
8	12.30	1.818*	12.65	12.75	12.45	12.05	12.10	11.55
9	12.30	4.500*	14.45	14.35	14.40	14.35	14.25	14.45
10	12.30	4.350*	14.20	14.20	14.20	14.00	13.95	13.95
11	12.30	4.350*	13.90	13.85	13.80	13.70	13.60	13.70
12	12.30	4.250*	13.35	13.30	13.25	13.15	13.05	13.10
13	12.30	1.330	14.50	14.50	14.60	14.55	14.50	14.55
14	12.30	1.330	14.60	14.60	14.55	14.45	14.50	14.40
15	12.30	1.330	14.10	14.00	14.05	13.95	13.95	14.00
16	12.30	1.330	12.55	13.55	13.45	13.35	13.45	13.50
17	12.30	2.100	14.50	14.50	14.45	14.45	14.50	14.45
18	12.30	1.940	14.60	14.60	14.65	14.60	14.55	14.60
19	12.30	1.880	13.95	13.90	14.00	13.95	13.90	13.90
20	12.30	1.880	13.55	13.45	13.50	13.50	13.35	13.30
21	12.30	2.662	14.60	14.60	14.55	14.55	14.50	14.50
22	12.30	2.662	14.40	14.45	14.55	14.30	14.30	14.25
23	12.30	2.662	14.25	14.25	14.40	14.30	14.10	14.05
24	12.30	2.655	13.25	13.35	13.55	13.50	13.05	12.95

* All numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE I OBSERVED DATA GROUP A (Continued) 1/4 THROTTLE

Run	t	N	W _f	SA	L	WB	DB	BP
1	8.95	505	0.40	29	20.00	79	94	29.00
2	7.75	525	0.42	29	21.00	79	94	29.00
3	8.52	500	0.54	29	19.15	79	94	29.00
4	7.27	500	0.30	29	18.90	79	94	29.00
5	7.57	1010	0.70	30	21.00	80	94	29.00
6	6.50	1022	0.70	30	29.40	80	94	29.00
7	6.18	1028	0.70	30	29.25	80	94	29.00
8	5.95	1032	0.70	30	29.10	80	94	29.00
9	7.43	1495	0.90	37	10.90	80	93	28.96
10	10.13	1515	1.40	37	26.05	80	93	28.96
11	6.00	1515	1.00	37	32.20	80	93	28.96
12	6.22	1505	1.10	37	32.20	80	93	28.96
13	6.84	2010	1.20	38	13.90	80	96	28.98
14	5.56	2015	1.20	38	31.90	80	96	28.98
15	5.23	2025	1.20	38	31.90	80	96	28.98
16	5.09	2000	1.20	38	32.50	80	96	28.98
17	5.40	2515	1.20	42	18.55	82	96	28.98
18	4.51	2505	1.20	42	29.55	82	96	28.98
19	4.33	2480	1.20	42	32.15	82	96	28.98
20	4.03	2500	1.20	42	30.85	82	96	28.98
21	7.08	3000	1.80	44	14.20	80	94	28.98
22	4.94	3020	1.40	44	23.20	80	94	28.98
23	4.80	2995	1.50	44	25.45	80	94	28.98
24	4.08	2990	1.30	44	25.90	80	94	28.98

TABLE I OBSERVED DATA GROUP A (Continued) 1/4 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	14.50	0.511*	13.85	13.60	13.60	13.55	13.40	13.65
2	14.10	0.555*	13.60	13.55	13.45	13.50	13.45	13.55
3	14.10	0.570*	13.35	13.30	13.30	13.10	12.70	12.90
4	14.10	0.534*	12.45	12.55	12.75	12.45	12.35	12.50
5	14.10	0.434	13.95	13.80	13.90	13.85	13.85	13.95
6	14.10	0.430	13.85	13.65	13.60	13.50	13.40	13.50
7	14.10	0.430	13.30	13.45	13.40	13.25	13.05	13.10
8	14.10	0.430	13.25	13.15	13.10	12.95	12.70	12.75
9	14.10	1.033	14.20	13.95	14.20	14.00	14.20	14.10
10	14.10	1.028	14.15	13.90	13.95	13.95	13.90	13.95
11	14.10	1.011	13.75	13.70	13.70	13.50	13.60	13.60
12	14.10	1.011	13.30	13.25	13.15	12.95	13.05	13.90
13	14.10	1.948	14.45	14.20	14.20	14.20	14.30	14.25
14	14.10	1.920	13.95	13.95	14.00	13.90	13.95	13.95
15	14.10	1.925	13.45	13.35	13.40	13.45	13.25	13.30
16	14.10	1.925	13.25	13.10	13.20	13.10	13.00	13.10
17	14.10	2.950	14.50	14.40	14.35	14.40	14.45	14.50
18	14.10	2.884	14.00	13.90	14.25	14.10	13.70	13.70
19	14.10	2.884	13.55	13.50	13.75	13.50	13.10	13.20
20	14.10	2.881	13.00	12.95	13.25	13.05	12.45	12.50
21	14.10	3.842	14.55	14.50	14.40	14.45	14.65	14.55
22	14.10	3.740	14.30	14.45	14.45	14.40	14.10	14.15
23	14.10	3.860	13.85	13.75	14.00	13.75	13.30	13.35
24	14.10	3.860	13.55	13.65	13.75	13.55	13.05	13.10

* All numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE I OBSERVED DATA GROUP A (Continued) 1/2 THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP
1	10.07	750	0.80	30	27.05	80	96	29.05
2	15.43	760	1.50	30	45.85	76	87	29.02
3	9.71	770	1.00	30	47.00	76	87	29.02
4	13.36	752	1.60	30	46.20	76	87	29.02
5	9.82	995	1.00	34	21.50	82	94	29.05
6	7.10	1005	1.00	34	48.75	76	88	29.02
7	6.44	1010	1.00	34	48.70	76	88	29.02
8	6.66	995	1.10	34	48.10	76	88	29.02
9	7.40	1542	1.30	38	34.60	82	94	29.02
10	4.75	1555	1.00	38	50.10	77	89	29.02
11	8.00	1550	1.90	38	52.15	77	89	29.02
12	4.37	1545	1.10	38	51.40	77	89	29.02
13	6.01	2000	1.40	40	40.10	83	94	29.05
14	5.42	1950	1.50	40	53.90	79	92	29.02
15	4.67	1930	1.40	40	53.90	79	92	29.02
16	5.67	1930	1.80	40	52.20	79	92	29.02
17	6.70	2530	1.80	40	29.50	83	94	29.05
18	3.78	2495	1.40	40	50.50	79	93	29.02
19	6.71	2492	2.70	40	52.35	77	91	29.02
20	4.52	2505	1.90	40	51.40	77	91	29.02
21	5.35	3070	1.70	40	26.95	82	95	29.05
22	5.62	3037	2.10	40	43.40	82	95	29.05
23	5.02	3050	2.20	40	44.80	80	96	29.05
24	6.95	3050	3.20	40	46.15	80	96	29.05

TABLE I OBSERVED DATA GROUP A (Continued) 1/2 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	17.75	0.400	13.90	13.80	13.75	13.80	13.85	13.95
2	17.75	0.407	13.30	13.80	14.00	13.70	13.40	13.20
3	17.75	0.404	13.15	13.10	13.25	13.50	12.90	13.15
4	17.75	0.389	12.30	12.40	12.80	12.65	11.00	12.10
5	17.75	0.765	13.95	13.85	13.85	13.90	13.90	14.00
6	17.75	0.735	13.75	13.55	13.65	13.55	13.25	13.45
7	17.75	0.721	12.55	12.30	12.50	12.30	11.80	12.05
8	17.75	0.721	12.95	12.75	13.05	12.85	12.40	12.65
9	17.75	2.075	14.20	14.20	14.25	14.25	14.35	14.30
10	17.75	1.770	14.20	14.25	13.95	13.65	13.40	13.60
11	17.75	1.787	13.55	13.40	13.10	12.65	12.30	12.50
12	17.75	1.787	12.90	12.75	12.55	12.10	11.70	12.05
13	17.75	3.504	14.30	14.40	14.25	14.25	14.35	14.25
14	17.75	3.016	13.90	13.85	13.80	13.45	13.25	13.25
15	17.75	2.982	13.45	13.40	13.25	12.85	12.45	12.55
16	17.75	2.962	12.75	12.80	12.70	12.30	11.75	11.70
17	17.75	4.700	14.10	14.25	14.20	14.15	14.35	14.25
18	17.75	4.975	13.75	13.65	13.65	13.50	13.15	13.05
19	17.75	4.985	13.10	12.75	12.85	12.55	11.95	12.30
20	17.75	4.910	12.50	12.25	12.35	12.10	11.35	11.45
21	17.75	6.300	14.25	14.50	14.30	14.35	14.35	14.10
22	17.75	6.300	14.15	14.25	14.25	14.15	14.10	14.10
23	17.75	6.300	13.10	12.95	13.05	13.15	12.60	12.65
24	17.75	6.400	12.75	12.70	12.85	12.60	12.15	12.25

TABLE I OBSERVED DATA GROUP A (Continued) FULL THROTTLE

Run	t	N	W _f	SA	L	WB	DB	BP
1	5.21	1192	1.50	26	102.9	75	88	29.04
2	4.30	1552	1.50	28	101.4	75	88	29.04
3	4.92	2002	2.00	32	92.2	82	98	29.04
4	4.13	2505	2.00	35	82.5	96	96	29.04
5	3.70	3015	2.00	38	69.4	95	95	29.04

OBSERVED DATA GROUP A FULL THROTTLE

Run	MP	h _w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	27.60	3.22	13.50	13.20	13.60	13.75	13.10	13.90
2	27.00	4.95	13.55	13.40	13.75	13.50	13.55	13.40
3	25.60	7.00	13.85	13.55	13.65	13.75	13.65	13.85
4	24.00	9.50	13.70	13.55	13.65	13.60	13.35	13.75
5	22.70	11.30	13.50	13.35	13.55	13.65	13.80	13.70

TABLE II CALCULATED DATA GROUP A NO LOAD

Run	Pounds fuel/hr.	A/Fc
1	1.80	14.25
2	1.65	12.76
3	1.66	12.10
4	1.99	11.13
5	3.74	16.80
6	3.72	13.50
7	3.83	12.77
8	4.37	11.30
9	5.30	17.28
10	5.22	14.60
11	5.33	13.62
12	5.43	13.00
13	7.39	15.92
14	7.15	15.10
15	7.42	13.80
16	7.89	12.70
17	9.14	16.50
18	8.90	15.17
19	9.01	14.80
20	9.21	13.72
21	11.77	15.24
22	11.35	14.10
23	11.73	13.70
24	11.88	13.47

TABLE II CALCULATED DATA GROUP A (Continued) 1/8 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	5.37	16.10	0.91
2	8.54	14.36	1.65
3	8.24	13.37	1.71
4	5.42	10.17	1.50
5	10.76	14.65	4.50
6	10.82	13.60	4.96
7	9.93	12.76	4.74
8	9.29	11.90	4.73
9	6.94	17.82	3.70
10	12.65	14.95	7.93
11	12.95	14.65	8.28
12	12.22	13.88	8.18
13	10.20	16.89	7.25
14	13.35	14.80	10.79
15	13.53	14.00	11.59
16	12.99	13.40	11.60
17	7.03	16.79	6.30
18	10.47	15.20	9.97
19	11.43	14.05	11.65
20	10.85	13.34	11.60
21	6.82	16.62	7.25
22	9.94	15.68	11.22
23	10.02	15.12	11.72
24	9.32	13.20	12.06

TABLE II CALCULATED DATA GROUP A (Continued) 1/4 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	11.63	16.40	2.36
2	11.82	15.72	2.53
3	10.60	13.79	2.76
4	7.90	10.90	2.40
5	12.00	13.60	5.30
6	14.50	13.35	7.50
7	13.70	12.70	7.55
8	13.32	12.20	7.50
9	7.05	18.40	4.07
10	14.92	16.05	9.85
11	15.30	13.20	12.20
12	14.30	12.45	12.10
13	8.30	17.34	6.98
14	15.80	14.00	16.10
15	14.75	13.20	16.20
16	14.40	12.83	16.25
17	10.98	16.88	11.66
18	14.50	13.92	18.50
19	15.05	13.40	19.90
20	13.36	12.42	19.30
21	8.78	16.75	10.65
22	12.95	14.15	17.60
23	12.75	13.71	12.05
24	12.70	13.42	19.38

TABLE II CALCULATED DATA GROUP A (Continued) 1/2 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	13.32	17.33	5.07
2	18.80	14.45	8.71
3	18.40	13.60	9.05
4	15.20	11.50	8.70
5	10.98	18.80	5.35
6	19.10	16.10	10.71
7	18.20	13.40	12.25
8	16.60	12.05	12.30
9	15.90	17.88	13.34
10	19.30	16.80	19.50
11	17.85	12.40	20.22
12	16.50	11.68	19.83
13	18.00	12.55	20.04
14	19.85	13.75	26.25
15	18.15	12.66	26.00
16	16.60	11.90	25.20
17	14.68	17.65	18.68
18	18.33	16.20	31.50
19	17.80	13.20	32.85
20	17.10	12.20	32.20
21	13.73	17.20	20.85
22	18.40	14.65	32.90
23	16.30	12.50	34.20
24	16.00	11.90	35.20

TABLE II CALCULATED DATA GROUP A (Continued) FULL THROTTLE

Run	Therm. Eff.	A/F_c	BHP	BHP _c
1	22.55	13.70	30.70	32.22
2	23.60	13.96	39.30	41.30
3	23.80	14.10	46.20	49.20
4	22.35	13.91	51.70	55.00
5	20.10	13.60	52.20	55.60

TABLE III OBSERVED DATA GROUP B NO LOAD

Run	t	N	Wf	SA	L	WB	DB	BP	Pa
1	13.13	400	0.30	20	NL	77	91	29.10	6.50
2	13.44	400	0.30	20	NL	76	91	29.10	5.30
3	11.94	400	0.30	20	NL	76	90	29.10	5.50
4	11.84	400	0.30	20	NL	76	90	29.10	6.00
5	6.37	1000	0.40	30	NL	74	92	29.13	8.10
6	6.53	1000	0.40	30	NL	74	92	29.13	8.60
7	6.82	1000	0.40	30	NL	74	92	29.13	9.60
8	6.79	1000	0.40	30	NL	74	92	29.13	10.00
9	4.91	1500	0.50	41	NL	71	86	29.13	6.80
10	5.58	1500	0.50	41	NL	71	86	29.13	10.20
11	6.03	1500	0.54	41	NL	71	86	29.13	9.80
12	6.83	1500	0.64	41	NL	70	87	29.13	10.00
13	4.77	2000	0.60	46	NL	70	88	29.13	9.90
14	5.06	2000	0.60	46	NL	70	88	29.13	10.00
15	5.01	2000	0.60	46	NL	70	88	29.13	10.00
16	4.93	2000	0.60	46	NL	70	88	29.13	7.60
17	4.87	2500	0.80	48	NL	72	90	29.13	8.40
18	5.11	2500	0.80	48	NL	72	90	29.13	9.00
19	4.55	2500	0.70	48	NL	72	90	29.13	8.80
20	4.35	2500	0.70	48	NL	73	90	29.13	10.00
21	3.73	3000	0.70	50	NL	73	91	29.13	7.50
22	3.77	3000	0.70	50	NL	73	91	29.13	9.50
23	3.71	3000	0.70	50	NL	73	91	29.13	9.80
24	3.55	3000	0.70	50	NL	73	91	29.13	9.90

TABLE III OBSERVED DATA GROUP B (Continued) NO LOAD

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	9.00	0.134*	13.50	13.50	13.55	13.60	13.60	13.60
2	9.00	0.103*	13.30	13.25	13.25	13.25	13.25	13.20
3	8.00	0.103*	13.10	13.05	13.00	12.85	12.80	12.75
4	8.00	0.110*	13.00	13.00	12.95	12.85	12.80	12.75
5	10.20	1.410*	13.85	13.95	13.90	13.85	13.90	13.90
6	10.00	1.238*	13.80	13.85	13.85	13.80	13.85	13.80
7	9.00	0.932*	13.70	13.70	13.80	13.75	13.80	13.80
8	8.00	0.717*	13.00	12.85	13.10	13.25	13.40	13.45
9	11.20	0.644	13.80	13.80	13.90	13.95	14.20	14.20
10	8.00	0.307	13.70	13.85	13.75	13.60	13.30	13.40
11	8.00	0.307	13.20	13.20	13.25	13.15	12.90	12.80
12	8.00	0.274	12.85	12.65	12.85	12.85	12.50	12.60
13	8.00	1.043	13.80	13.85	13.95	14.00	14.20	14.20
14	8.00	0.643	14.20	14.40	14.30	13.95	13.25	13.30
15	8.00	0.560	13.80	14.20	13.80	13.45	12.80	12.85
16	10.50	0.483	13.15	13.15	12.85	12.45	11.85	11.90
17	10.50	1.481	14.25	14.25	14.35	14.35	14.40	14.50
18	9.00	1.241	14.60	14.55	14.60	14.55	14.30	14.40
19	8.50	0.965	14.45	14.50	14.20	13.90	13.25	13.25
20	8.00	0.876	13.60	13.55	13.15	12.85	12.10	12.10
21	10.00	1.910	14.40	14.35	14.45	14.50	14.35	14.45
22	8.50	1.399	14.30	14.35	13.90	13.65	13.10	13.00
23	8.50	1.200	13.70	13.65	13.45	13.10	12.50	12.50
24	8.50	1.260	13.00	13.00	12.80	12.45	12.00	12.00

* All numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE III OBSERVED DATA GROUP B (Continued) 1/8 THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP	P_a
1	7.02	510	0.30	29	18.60	75	92	29.03	7.70
2	7.20	540	0.40	29	22.30	75	93	29.03	7.70
3	6.12	540	0.40	29	21.95	75	93	29.03	7.70
4	7.50	1000	0.62	36	17.20	75	94	29.03	7.20
5	6.47	1025	0.60	36	27.20	75	94	29.03	7.30
6	5.76	1000	0.60	36	29.60	75	94	29.03	7.40
7	5.13	1005	0.60	36	29.10	75	94	29.03	7.20
8	6.05	1505	0.70	44	12.10	76	95	29.03	7.70
9	5.47	1510	0.70	44	23.95	76	95	29.03	7.70
10	5.27	1500	0.72	44	27.80	76	95	29.03	7.70
11	5.30	1510	0.78	44	29.10	76	95	29.03	7.70
12	6.81	2000	1.14	47	21.25	76	97	29.03	7.70
13	5.50	2000	1.00	47	25.30	76	97	29.03	7.70
14	4.58	2000	0.90	47	28.30	76	97	29.03	7.70
15	7.22	2020	1.52	47	28.05	76	97	29.03	7.70
16	6.09	2500	1.20	50	12.35	77	94	29.03	7.70
17	4.93	2490	1.00	50	18.05	77	94	29.03	7.70
18	4.55	2510	1.00	50	22.40	77	94	29.03	7.70
19	4.81	2525	1.20	50	26.05	77	94	29.03	7.70
20	5.13	2990	1.30	50	17.95	70	84	29.13	7.70
21	4.05	3010	1.10	50	20.10	70	84	29.13	7.70
22	3.14	2990	0.90	50	21.60	70	84	29.13	7.70
23	3.88	3000	1.20	50	21.60	70	84	29.13	7.70

TABLE III OBSERVED DATA GROUP B (Continued) 1/8 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	12.30	0.526*	13.60	13.65	13.60	13.55	13.55	13.60
2	12.30	0.526*	13.25	13.15	13.20	13.25	13.25	13.25
3	12.30	0.526*	13.10	12.85	12.95	13.05	13.10	13.05
4	12.30	2.255*	13.85	13.95	13.90	13.85	13.95	13.90
5	12.30	2.255*	14.20	14.40	14.30	14.15	13.85	13.85
6	12.30	2.181*	13.55	13.55	13.60	13.45	12.90	13.00
7	12.30	2.181*	12.25	12.20	12.55	12.50	11.80	11.80
8	12.30	0.836	14.15	14.15	14.10	14.00	14.05	14.00
9	12.30	0.836	14.40	14.40	14.40	14.40	14.40	14.35
10	12.30	0.820	14.00	13.95	14.30	14.50	14.45	14.45
11	12.30	0.820	13.65	13.65	13.95	14.05	13.85	13.85
12	12.30	1.624	14.60	14.60	14.55	14.60	14.65	14.65
13	12.30	1.589	14.65	14.65	14.65	14.65	14.60	14.55
14	12.30	1.589	13.95	13.85	13.95	14.10	13.75	13.80
15	12.30	1.589	13.40	13.40	13.60	13.50	13.25	13.15
16	12.30	2.420	14.65	14.60	14.55	14.55	14.65	14.55
17	12.30	2.420	14.65	14.60	14.55	14.50	14.55	14.55
18	12.30	2.440	14.75	14.75	14.70	14.70	14.70	14.75
19	12.30	2.415	13.60	13.50	13.95	14.00	13.55	13.65
20	12.30	2.900	15.00	14.95	14.90	14.80	14.40	14.50
21	12.30	2.900	14.25	14.10	14.70	14.60	13.70	13.74
22	12.30	2.900	13.55	13.40	14.20	13.95	13.00	12.95
23	12.30	2.900	12.45	12.40	13.35	13.15	12.00	12.10

* All numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE III OBSERVED DATA GROUP B (Continued) 1/4 THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP	P_a
1	5.75	530	0.27	30	22.40	79	92	29.05	8.40
2	6.06	560	0.30	30	24.50	79	92	29.05	8.40
3	7.07	600	0.40	30	28.00	79	92	29.05	7.90
4	6.70	610	0.50	30	28.90	79	92	29.05	7.90
5	6.96	1000	0.60	30	19.50	77	96	29.08	5.40
6	5.29	995	0.50	30	30.25	77	96	29.08	5.40
7	5.02	997	0.50	30	35.00	77	96	29.08	5.40
8	4.63	1002	0.50	30	36.00	77	96	29.08	5.40
9	6.44	1510	0.90	38	26.50	78	95	29.08	5.40
10	5.33	1525	0.80	38	33.50	78	95	29.08	5.40
11	3.35	1500	0.50	38	33.80	78	95	29.08	7.70
12	4.72	1500	0.80	38	38.50	78	94	29.08	8.90
13	5.64	2000	1.00	44	24.10	78	91	29.08	4.40
14	5.22	1995	1.00	44	32.30	78	91	29.08	4.40
15	8.69	1990	1.80	44	35.00	78	91	29.08	4.40
16	3.55	2000	0.80	44	38.70	78	91	29.08	10.90
17	6.03	2500	1.40	50	26.20	80	94	29.10	4.30
18	5.20	2505	1.30	50	32.30	79	92	29.10	4.40
19	4.86	2500	1.30	50	35.55	79	92	29.10	7.40
20	3.88	2495	1.10	50	36.70	79	95	29.10	11.90
21	3.95	3020	1.10	50	23.80	71	85	29.13	7.70
22	3.92	2990	1.22	50	31.30	71	85	29.13	7.70
23	3.01	3010	1.00	50	32.50	72	86	29.13	7.70
24	3.41	2990	1.20	50	33.50	72	86	29.13	7.70

TABLE III OBSERVED DATA GROUP B (Continued) 1/4 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	14.10	0.854*	14.05	14.10	14.05	14.10	14.05	14.10
2	14.10	0.854*	13.90	13.95	13.90	13.90	13.90	13.95
3	14.10	0.854*	13.80	13.90	13.90	13.90	13.90	13.95
4	14.10	0.854*	12.45	11.20	12.30	12.65	12.50	12.60
5	14.10	0.478	14.10	14.15	14.15	14.20	14.25	14.20
6	14.10	0.478	14.50	14.50	14.50	14.55	14.65	14.55
7	14.10	0.478	14.45	14.45	14.45	14.35	14.30	14.35
8	14.10	0.478	13.85	13.85	13.90	13.82	13.60	13.60
9	14.10	1.090	14.60	14.60	14.55	14.60	14.60	14.55
10	14.10	1.090	14.75	14.65	14.65	14.75	14.75	14.65
11	14.10	1.090	14.40	14.25	14.45	14.50	14.40	14.45
12	14.10	1.090	13.60	13.60	13.85	13.85	13.70	13.75
13	14.10	1.896	14.75	14.75	14.70	14.65	14.70	14.65
14	14.10	1.896	14.80	14.85	14.80	14.80	14.80	14.80
15	14.10	1.896	14.40	14.40	14.60	14.70	14.60	14.60
16	14.10	1.896	13.65	13.60	13.90	13.90	13.60	13.60
17	14.10	3.300	14.40	14.40	14.35	14.40	14.40	14.35
18	14.10	3.300	14.50	14.45	14.40	14.40	14.45	14.45
19	14.10	3.100	14.05	13.90	14.30	14.45	14.10	14.20
20	14.10	3.340	13.75	13.65	14.10	14.05	13.45	13.45
21	14.10	4.300	14.85	14.85	14.70	14.75	14.85	14.85
22	14.10	4.300	14.75	14.50	14.75	14.50	13.80	13.85
23	14.10	4.300	13.90	13.75	14.45	14.15	13.20	13.30
24	14.10	4.300	13.05	13.10	13.80	13.50	12.60	12.55

* Numbers followed by the asterisk are pressure drops across the orifice of 1.00 inch diameter.

TABLE III OBSERVED DATA GROUP B (Continued) 1/2 THROTTLE

Run	t	N	W _f	SA	L	WB	DB	BP	P _a
1	7.00	825	0.64	30	31.70	79	95	28.90	11.25
2	6.76	845	0.70	30	43.45	79	95	28.90	11.25
3	6.52	790	0.70	30	50.90	79	95	28.90	10.75
4	6.00	800	0.70	30	52.25	79	95	28.90	11.25
5	5.02	1000	0.50	38	25.80	78	92	28.95	4.75
6	4.45	1010	0.50	38	43.35	78	92	28.95	4.75
7	5.55	1010	0.70	38	52.90	78	93	28.95	4.75
8	5.70	1020	0.80	38	54.70	78	93	28.95	4.75
9	5.74	1530	1.00	42	45.70	80	94	28.98	5.25
10	4.80	1525	0.90	42	51.40	80	94	28.98	5.15
11	5.02	1515	1.00	42	54.05	80	95	28.98	5.15
12	4.84	1520	1.00	42	54.45	80	95	28.98	5.15
13	5.39	2000	1.20	45	42.00	79	95	28.98	5.15
14	4.71	2005	1.10	45	46.85	79	95	28.98	5.25
15	5.08	2010	1.30	45	52.70	79	95	28.98	5.25
16	4.41	2000	1.20	45	54.30	79	95	28.98	5.05
17	5.52	2500	1.60	50	41.70	79	92	29.02	5.15
18	4.53	2500	1.40	50	49.15	79	92	29.02	5.25
19	3.39	2505	1.10	50	51.15	80	93	29.02	5.25
20	3.43	2495	1.20	50	51.75	80	93	29.02	4.75
21	4.07	2990	1.40	50	32.50	79	93	29.02	4.55
22	3.61	3000	1.30	50	44.60	79	93	29.02	4.75
23	3.34	3000	1.32	50	47.50	79	93	29.02	4.75
24	3.74	2990	1.60	50	49.60	79	93	29.02	4.75

TABLE III OBSERVED DATA GROUP B (Continued) 1/2 THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	17.25	0.481	13.80	13.85	13.85	13.85	13.95	13.95
2	17.25	0.504	13.35	13.90	13.90	13.60	13.20	13.35
3	17.25	0.530	13.35	13.85	13.70	13.40	12.90	12.80
4	17.25	0.530	13.45	13.85	13.75	13.15	11.80	11.45
5	17.25	0.774	14.00	14.05	14.05	14.10	14.20	14.05
6	17.25	0.793	14.35	14.40	14.40	14.40	14.50	14.50
7	17.25	0.793	14.55	14.65	14.60	14.50	14.45	14.60
8	17.25	0.793	13.65	13.85	14.30	14.00	13.55	13.60
9	17.25	1.672	14.55	14.50	14.45	14.45	14.55	14.55
10	17.25	1.702	14.70	14.70	14.65	14.60	14.50	14.50
11	17.25	1.689	14.35	14.30	14.45	14.25	13.80	13.80
12	17.25	1.689	13.90	13.90	14.25	14.05	13.60	13.45
13	17.25	3.220	14.25	14.25	14.20	14.20	14.30	14.15
14	17.25	3.262	14.45	14.35	14.30	14.35	14.40	14.40
15	17.25	3.262	14.55	14.40	14.40	14.40	14.40	14.30
16	17.25	3.178	13.95	13.85	14.20	14.30	13.95	13.90
17	17.25	5.445	14.50	14.40	14.40	14.35	14.40	14.35
18	17.25	5.285	14.50	14.50	14.40	14.35	14.45	14.40
19	17.25	5.285	14.30	14.20	14.25	14.35	14.35	14.35
20	17.25	5.150	13.60	13.60	14.10	14.20	13.85	13.85
21	17.25	6.900	14.45	14.35	14.20	14.20	14.25	14.35
22	17.25	6.800	14.60	14.45	14.50	14.50	14.40	14.45
23	17.25	6.800	13.85	13.75	13.85	14.30	13.85	13.85
24	17.25	6.800	12.95	12.90	13.15	13.70	13.50	13.10

TABLE III OBSERVED DATA GROUP B (Continued) FULL THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP	P_a
1	3.32	1140	1.00	23	102.9	73	87	29.10	0
2	4.29	1510	1.80	37	103.3	73	87	29.10	0
3	5.78	2000	3.00	41	100.2	73	87	29.10	0
4	3.76	2500	2.10	47	87.0	73	87	29.10	0
5	4.37	3000	2.60	51	77.5	73	87	29.10	0

OBSERVED DATA GROUP B FULL THROTTLE

Run	MP	h_w	A/F-1	A/F-2	A/F-3	A/F-4	A/F-5	A/F-6
1	28.00	2.895	14.65	13.25	10.50	10.50	12.95	14.60
2	27.00	4.500	14.95	12.55	10.50	10.50	12.65	15.20
3	26.00	7.500	15.00	13.10	12.60	10.60	10.60	15.20
4	24.00	9.400	14.65	14.65	12.70	11.75	13.30	14.70
5	23.00	12.10	14.65	13.75	12.00	12.00	13.45	14.60

TABLE IV CALCULATED DATA GROUP B NO LOAD

Run	Pounds fuel/hr.	A/F _c
1	1.370	15.15
2	1.340	13.56
3	1.508	12.14
4	1.520	11.20
5	3.765	17.90
6	3.675	17.19
7	3.250	15.58
8	3.540	13.65
9	6.110	17.40
10	5.380	13.69
11	5.380	13.70
12	5.640	12.32
13	7.600	17.95
14	7.110	14.90
15	7.190	13.78
16	7.310	12.60
17	9.850	16.30
18	9.400	15.69
19	9.240	14.04
20	9.650	12.80
21	11.270	16.15
22	11.130	13.58
23	11.310	13.10
24	11.820	12.20

TABLE IV CALCULATED DATA GROUP B (Continued) 1/8 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	11.60	16.05	2.38
2	11.32	12.32	3.01
3	9.48	10.47	2.96
4	10.88	17.10	4.30
5	15.72	15.23	6.97
6	14.86	13.47	7.40
7	13.10	11.98	7.30
8	8.22	18.70	4.56
9	14.80	15.60	9.03
10	15.92	15.00	10.42
11	15.56	13.41	10.98
12	13.26	15.82	10.62
13	14.52	15.10	12.67
14	15.06	13.98	14.15
15	14.10	13.04	14.17
16	8.18	17.28	7.73
17	11.60	16.77	11.22
18	13.36	15.50	14.08
19	13.80	13.57	16.50
20	11.06	14.88	13.40
21	11.63	13.89	15.10
22	11.78	13.13	16.12
23	10.96	12.16	16.20

TABLE IV CALCULATED DATA GROUP B (Continued) 1/4 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	13.20	18.55	2.97
2	14.50	17.59	3.43
3	15.50	15.40	4.20
4	12.35	11.67	4.41
5	11.82	17.50	4.88
6	16.62	15.93	7.52
7	18.30	15.13	8.72
8	17.50	13.97	9.00
9	14.95	16.33	10.00
10	17.70	15.22	12.76
11	17.70	15.32	12.68
12	17.80	13.50	14.42
13	14.20	16.94	12.05
14	17.60	15.70	16.10
15	17.80	14.50	17.43
16	17.90	13.32	19.32
17	14.72	17.02	16.40
18	16.90	15.83	20.20
19	17.33	14.40	22.20
20	16.88	14.08	22.90
21	13.50	16.42	18.00
22	15.75	14.70	23.40
23	15.40	13.79	24.45
24	14.86	13.00	25.05

TABLE IV CALCULATED DATA GROUP B (Continued) 1/2 THROTTLE

Run	Therm. Eff.	A/F _c	BHP
1	14.93	17.38	6.54
2	18.55	15.32	9.14
3	19.55	14.10	10.08
4	18.70	13.30	10.45
5	13.52	19.25	6.44
6	20.40	17.30	10.95
7	22.10	15.38	13.33
8	20.80	13.82	13.95
9	21.00	16.60	17.50
10	21.95	15.16	19.60
11	21.50	14.20	20.50
12	20.90	13.68	20.65
13	19.70	17.52	21.00
14	21.00	16.85	23.45
15	21.65	15.38	26.45
16	20.85	14.22	27.15
17	18.80	17.55	26.10
18	20.80	16.20	30.75
19	20.62	15.42	32.00
20	19.26	14.20	32.25
21	11.13	16.69	24.25
22	19.42	15.78	33.55
23	18.82	14.40	35.60
24	18.10	13.30	37.10

TABLE IV CALCULATED DATA GROUP B (Continued) FULL THROTTLE

Run	Therm. Eff.	A/F_c	BHP	BHP_c
1	20.45	12.30	29.30	30.80
2	19.50	11.15	39.10	41.10
3	20.20	11.63	50.20	52.90
4	20.35	12.10	54.40	57.10
5	20.40	12.90	58.20	61.20

TABLE V OBSERVED DATA GROUP C 1/8 THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP	h_w	MP
1	3.90	1000	0.30	30	12.80	69	83	29.11	0.444	12.30
2	3.52	1000	0.30	30	24.00	69	83	29.11	0.440	12.30
3	3.22	1000	0.30	30	25.90	69	83	29.11	0.440	12.30
4	2.84	1000	0.30	30	25.90	70	84	29.11	0.444	12.30
5	2.69	1500	0.30	39	14.40	70	84	29.11	1.009	12.30
6	2.38	1500	0.30	39	24.80	70	84	29.11	1.009	12.30
7	2.18	1500	0.30	39	28.90	70	84	29.11	1.009	12.30
8	2.00	1500	0.30	39	28.90	70	84	29.11	1.009	12.30
9	2.71	2000	0.42	44	12.40	70	84	29.11	1.919	12.30
10	2.42	2000	0.40	44	22.20	70	84	29.11	1.919	12.30
11	2.15	2000	0.40	44	28.20	70	84	29.11	1.919	12.30
12	2.43	2000	0.50	44	28.60	70	84	29.11	1.846	12.30

OBSERVED DATA GROUP C 1/4 THROTTLE

Run	t	N	W_f	SA	L	WB	DB	BP	h_w	MP
1	3.61	1000	0.30	30	17.90	70	84	29.11	0.449	14.10
2	2.07	1000	0.20	30	34.70	70	84	29.11	0.449	14.10
3	1.96	1000	0.20	30	36.40	70	84	29.11	0.449	14.10
4	2.53	1000	0.30	30	36.40	70	84	29.11	0.449	14.10
5	2.52	1500	0.32	37	17.20	79	94	28.95	1.143	14.10
6	2.10	1500	0.30	37	32.30	79	94	28.95	1.143	14.10
7	1.78	1500	0.30	37	37.10	79	94	28.95	1.130	14.10
8	2.85	2000	0.50	39	20.60	79	94	28.95	2.055	14.10
9	2.54	2000	0.50	39	32.00	79	94	28.95	2.055	14.10
10	3.18	2000	0.70	39	36.70	79	94	28.95	2.055	14.10
11	2.14	2000	0.50	39	37.90	79	94	28.95	2.055	14.10

TABLE VI CALCULATED DATA GROUP C 1/8 THROTTLE

Run	Therm. Eff.	A/F _c
1	8.68	19.18
2	14.70	14.21
3	14.52	15.78
4	12.90	14.00
5	10.10	19.91
6	15.40	17.62
7	16.45	16.12
8	15.12	14.82
9	8.35	17.70
10	14.00	16.60
11	16.40	14.75
12	15.00	13.10

CALCULATED DATA GROUP C 1/4 THROTTLE

Run	Therm. Eff.	A/F _c
1	11.26	17.82
2	18.70	15.34
3	18.60	14.52
4	16.00	12.54
5	10.60	18.37
6	17.70	16.30
7	17.40	13.75
8	12.30	17.80
9	17.25	15.88
10	17.40	14.20
11	16.98	13.33

APPENDIX III
SAMPLE CALCULATIONS

APPENDIX III SAMPLE CALCULATIONS

A. Brake Horsepower-BHP

From the general equation

$$\text{BHP} = \frac{2\pi \text{LRN}}{33000}$$

R (Length of dynamometer arm) is designed by the manufacturer so that

$$\text{BHP} = \frac{\text{LN}}{4000}$$

B. Thermal efficiency-therm. eff.

$$\text{Therm. eff.} = \frac{\text{BHP} \times 2545}{W_f \times \frac{60}{t} \times q_f}$$

C. Pounds of fuel per hour = $W_f \times \frac{60}{t}$

D. Air-fuel ratio (Calculated) -A/F_c

1. For orifice of 1.50 inch diameter:

$$A/F_c = 8.02 C_d F A \sqrt{\frac{P_1 - P_2}{v_1}} \times \frac{t}{W_f} \times 60 \quad 1$$

where: C_d = discharge coefficient

F = approach factor ($C_d \times F = 0.616$)

A = area of thin plate orifice

P_1 = absolute pressure before orifice,
pounds/foot².

P_2 = absolute pressure after orifice,
pounds/foot².

¹Ebaugh, Newton C., Engineering Thermodynamics,
New York: D. Van Nostrand Company, Inc., 1937. pp 117-120.

v_1 = specific volume of air at room conditions, cubic feet/pound.

Substituting these values, the expression becomes

$$A/F_c = 8.4 \sqrt{\frac{h_w}{v_1}} \times \frac{t}{W_f}$$

The values of h_w (pressure drop across orifice in inches of water) was corrected for the variation of the specific weight of water with temperature.

2. The expression for A/F_c for the orifice of 1.00 inch diameter was arrived at in a similar manner.

$$A/F_c = 3.63 \sqrt{\frac{h_w}{v_1}} \times \frac{t}{W_f}$$

- E. Brake horsepower corrected to standard conditions²
(29.92 "Hg. and 60°F)-BHP_c

$$BHP_c = BHP \times \frac{P_s}{P_a} \sqrt{\frac{t_a}{t_s}}$$

where: P_s = standard atmospheric pressure,
29.92"Hg.

P_a = atmospheric pressure during test
run, "Hg.

t_a = room temperature during test
run, °R.

t_s = standard atmospheric temperature
520°R.

²Jennings, Burgess H., and Obert, Edward F., Internal Combustion Engines, Scranton, Pennsylvania: International Textbook Company, 1944. pp 42-43.